

Communications Payload Concepts for Geostationary Facilities

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COMMUNICATIONS PAYLOAD CONCEPTS FOR GEOSTATIONARY FACILITIES

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SUMMARY

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The results of two NASA-sponsored studies that defined possible communications payload concepts for geostationary facilities are summarized and presented. The studies were performed by the Ford Aerospace and Communications Corporation - Western Development Laboratory (FACC) and by RCA Astro-Electronics (RCA).¹ The objectives of the study were to determine the types of communications payloads that would be appropriate for a large geostationary facility initially operational in the late 1990's, to provide conceptual designs, descriptions, and comparisons of such payloads implemented on a single spacecraft, and to indicate the enabling and supporting high-risk technology development efforts required for implementation.

After a data-base development effort, FACC and RCA generated 8 and 10 payload concepts, respectively, involving various combinations of communications services. From these NASA selected five FACC and four RCA concepts for more in-depth development. The results of these efforts are described herein. Both contractors concluded that aggregating communications services on a single geostationary facility appeared to be more cost effective than using several smaller satellites. However, for some concepts implementation is more difficult because of greater institutional, regulatory, and insurance barriers. FACC identified their scenario V as the most viable of the concepts they developed in detail. This concept is basically a high-capacity continental United States (CONUS) coverage facility using C-, Ku-, and Ka-band frequencies to provide 72 Gb/s of trunking and customer premises services. Seven of these facilities could provide 100 percent of the projected CONUS satellite-addressable demand with the exception of mobile and broadcast television for the year 2008. Of the four concepts developed in detail by RCA, they ranked a land mobile satellite service concept first. (Work on this contract was performed before the Federal Communications Commission (FCC) decision to limit land mobile frequencies to L-band. RCA's concept uses both L-band and ultrahigh frequency (UHF).) This concept would provide 100 percent of the 1998 CONUS and Canadian satellite-addressable demand for mobile radiotelephone (voice) and digital data services (paging and dispatch). A 30-m-diameter antenna is a significant feature of this payload concept.

The contractors identified several technological developments as desirable for payload implementation. These include dual polarization reuse at Ka band; lightweight, high-speed, high-efficiency baseband processors; large unfurlable antennas; and intersatellite links.

¹Now GE-RCA Astro-Space Division.

INTRODUCTION

Two parallel contracts that defined potential operational communications payloads for geostationary platforms were recently completed for the NASA Lewis Research Center. The contracts were performed by the Ford Aerospace and Communications Corporation - Western Development Laboratory (FACC) and by RCA Astro-Electronics (RCA). The detailed results of these studies, performed in 1984 and 1985, are in the contractors' reports (refs. 1 and 2). Satellite Systems Engineering, Inc., of Bethesda, Maryland, served as a subcontractor to FACC, and Comsat Laboratories of Clarksburg, Maryland, was a subcontractor to RCA.

This report is a single-source summary and comparison of the FACC and RCA efforts. The background events leading to the subject studies are briefly reported. The studies are then described, and the results presented and compared. The findings are discussed and suggestions are made for follow-on work.

BACKGROUND

Studies performed in the late 1970's and early 1980's (refs. 3 to 9) have indicated that large geostationary systems, such as platforms or satellite clusters, may use the orbital arc and spectrum resource more efficiently than single satellites. Such systems could also provide the capabilities needed for new communications services (e.g., high power for direct broadcast satellite services (DBS) and large antenna apertures for future mobile satellite services). In addition, the platform studies have also indicated that economies of scale might be obtained, thus making a single large facility more economically attractive than a number of smaller satellites. However, critiques of the platform study results (e.g., ref. 10), although not refuting the possible benefits of platforms, have suggested that a number of technical, economic, regulatory, and institutional questions need further study before platform design and development efforts are continued.

Several more recent developments have affected the results and conclusions of the early platform studies. Some of these developments reduced demand on the arc/spectrum resource (e.g., the decrease in allowed orbital spacing of satellites to 2° and increases in the voice and video capacities of transponders). Other developments, such as (refs. 11 to 14) 1983 and 1984 traffic forecasts and models (including customer premises services (CPS) and new services such as high-power DBS), had the potential for increasing demand on the arc/spectrum. It was important therefore to continue studies of large geostationary communications facility concepts in order to address the issues raised by industry critiques and to include the effects of recent developments and study results.

Accordingly, the studies described in this report were part of the first phase of a potential four-phase NASA effort. The objectives of the studies were to determine and describe the types of operational payloads, if any, that would be appropriate for a large geostationary communications facility in the mid to late 1990's. Payloads involving telephone trunking, data distribution, and networking, video distribution, and direct broadcast service were to be considered with emphasis on U.S. domestic services. Payloads for international services were also to be considered by directly using the platform to provide such services (to International Telecommunications Union (ITU) Region 2) or by

using intersatellite links to international satellites or non-U.S. platforms (to Europe, Africa, or Asia).

Parallel studies, under the sponsorship of the NASA Marshall Space Flight Center (MSFC), were to examine the noncommunications aspects of the platform (i.e., the spacecraft (bus), transportation, and space operations systems). These studies were performed by FACC and by the Lockheed Missiles and Space Company (LMSC). The outputs of the bus studies and the communications payload studies were to be used in subsequent system-tradeoff studies to determine the best, if any, operational system and its associated high-risk technology development needs. These combined efforts were to provide NASA with answers to the following questions:

(1) Is the existence of one or more large geostationary facilities (very large satellites, platforms, or clusters of satellites), each with a payload providing a single communications service or a variety of communications services, desirable in the mid to late 1990's?

(2) If so, what is (are) the most viable operational system (systems), consisting of payload, spacecraft, transportation, and space operations subsystems, for that timeframe?

(3) What enabling and supporting technologies are required before these operational systems can be implemented? In particular, which of these technologies involve high technical or economic risk?

(4) What are the proper industry and NASA roles in developing and demonstrating these technologies?

The operational system studies have been postponed. After the communications payload studies had been completed, NASA began a follow-on effort to consider additional platform payloads and to identify and define potential science payloads for a geosynchronous-Earth-orbiting (GEO) platform. This effort is currently under way. The rapid implementation of terrestrial, long-haul fiber optics networks and the corresponding estimated capture of the U.S. trunking markets are not accounted for in the studies. The rapid growth of the very small aperture terminal (VSAT) market and the potential for satellites with onboard processing and switching to bypass the terrestrial networks were also unforeseen.

SUMMARY OF CONTRACTOR RESULTS

Ford Aerospace and Communications Corporation

Five platform payload aggregations were developed in detail by FACC and four by RCA during the course of the study. The five FACC scenarios, selected from an initial list of 10, consisted of the following:

(1) Scenario II: Medium-capacity CONUS fixed satellite service (FSS) trunking and medium-power DBS capability

(2) Scenario IV: High-capacity medium- and high-power video distribution and DBS capability

(3) Scenario V: High-capacity CONUS FSS trunking and CPS capability

(4) Scenarios VI-A and VI-B: Complementary pair of facilities with high-capacity CONUS FSS payload that incorporates intersatellite links (ISL) to European and Asian platforms, Region 2 international and non-U.S. domestic payloads, and maritime payloads

The characteristics of these scenarios are summarized briefly in table 1, with more detail given later in this report.

FACC drew a number of conclusions as a result of the study:

(1) Large facilities may provide significant economies of scale. FACC estimates a factor of 4 or 5 cost advantage for a large facility over a number of small individual satellites providing equivalent services. Of the total savings, 40 percent come from reduced launch costs, 30 percent from reduced bus costs, and 30 percent from reduced payload costs. FACC based these estimates on the detailed costs developed for the payloads and on estimates of current or projected launch and spacecraft costs.

(2) A constellation of seven scenario V (high-capacity CONUS FSS trunking and CPS) facilities could handle all the projected year 2008 U.S. domestic satellite traffic, with the exception of broadcast video and mobile. FACC considered scenario V the most viable concept of the five scenarios examined in detail. In addition to the cost advantage over multiple smaller satellites cited above, the scenario involves a minimum of regulatory and institutional barriers to implementation, a balance of digital and analog capability based on the projected demand for each, and the capability of being owned and operated by a single large carrier instead of a consortium.

(3) Scenarios VI-A and VI-B can serve all the year 2008 projected Region 2 non-U.S. traffic with one facility of each type. However, these complementary facilities ranked fourth and fifth of the five examined in detail. Institutional barriers are more of a problem here, particularly with respect to control of a facility providing domestic and international services to a number of different countries. Although economies of scale are present, the implementation cost may be too high for any single carrier or consortium of carriers, bringing overall economic viability into question.

(4) In developing the various scenarios, FACC found a number of technological advances to be desirable. The highest on FACC's list of desired advances was polarization tracking at Ka band to enable full reuse at high-traffic-density centers of the 2.5-GHz bandwidth available. Second on FACC's list was high-speed, high-efficiency baseband processors. Others included onboard analog-to-digital (A/D) conversion, intersatellite links, and various antenna developments.

In most cases, the desired technological advances are applicable to ordinary communications satellites as well as to larger geostationary facilities.

RCA Astro-Electronics Division

The selection of the four RCA platform payload aggregations that were subsequently developed and defined in terms of payload concepts was driven by a set of criteria that addressed issues of concern to the communications satellite industry. The characteristics of the concepts are summarized in table 2 and consisted of the following:

- (1) Concept 1: High-capacity land mobile satellite service (LMSS) for voice and digital data services to CONUS and Canada via UHF and L band (Subsequent to the studies the FCC limited land mobile services to L band.)
- (2) Concept 2: High-capacity CONUS FSS payload
- (3) Concept 3: Medium-capacity CONUS FSS and small-capacity CONUS video distribution payload
- (4) Concept 4: Multipurpose scenario with high-capacity CONUS FSS payload that incorporates ISL to European and Asian satellites and also tracking and data acquisition (TDAS) payload

Some of the conclusions drawn by RCA are as follows:

(1) Aggregation of communications payloads might make capacity available at a somewhat lower cost per transponder. A more detailed costing analysis is needed to verify the cost advantages.

(2) Large geostationary communications facilities with multiple payloads and multiple frequency bands (C, Ku, and Ka) can improve system utilization through frequency cross-strapping.

(3) A growing demand for satellite communications services could result in the development of communications spacecraft of increasing capacity that would reach "platform size" through an evolutionary process (i.e., 10-yr process).

(4) A constellation of several facilities could provide all U.S. projected satellite traffic for the year 2008, thus significantly reducing the current and projected number of standard satellites.

(5) Several current and future factors will affect the development of the large geostationary facility. Some of these factors include market uncertainties, especially those due to the competition from terrestrial fiber optics, risks of placing a large amount of capacity on one spacecraft, multicompany or single-company ownership, and regulatory issues, especially for international ventures.

(6) Large communications facilities will require the development of cer-

tain critical technologies. Antenna developments, especially the 30-m-diameter UHF/L-band antenna for the LMSS concept, were rated as having the highest combined technical risk and cost uncertainty. Other critical developments include efficient, lightweight baseband processors, large intermediate-frequency (IF) switch matrices, intersatellite links, and solid-state, high-power amplifiers.

PAYLOAD STUDY DESCRIPTION

The studies consisted of the following seven tasks performed under various general and specific guidelines:

- (1) Initialization and data base development
- (2) Communications service aggregation scenario development
- (3) Payload concept development
- (4) Payload definition
- (5) Costing
- (6) Critical technology development
- (7) System comparisons

Task 1 entailed developing a data base to be used in later tasks, generating evaluation criteria to be used at several decision points, and generating additional study guidelines and constraints to supplement, as appropriate, those given by NASA. The data base included communications traffic forecasts and models, space and terrestrial plant-in-place information and forecasts, and forecasts of 1998 technology. Evaluation criteria were generated to aid in selecting various communications service aggregation scenarios for further development in the study and to evaluate payload concepts developed from the selected service aggregation scenarios.

A minimum of six communications service aggregation scenarios were to be developed in task 2. The scenarios were to describe potential groupings of voice, video, and data services that would maximize the communications service capacity of a single geostationary orbital location and would make sense commercially. At least two of these scenarios were to satisfy a set of baseline conditions; and at least two, a set of conditions that were a variation from the baseline. These conditions are discussed later in this section. The scenarios were to be ranked according to the evaluation criteria.

In task 3 at least four payload concepts were to be developed and communications architectures described for those service aggregation scenarios selected in task 2. Again, at least two concepts were to satisfy the baseline conditions; and at least two, the variations to the baseline. The concepts were then to be ranked according to various criteria.

In task 4 the configurations and characteristics were to be defined for the concepts and architectures ranked in task 3. The configurations were to be subject to the constraints imposed by the use of one of two launch concepts. These concepts are briefly described later in this section. Also, to be described was how in-orbit payload servicing would affect the various payload characteristics and the payload requirements on the spacecraft and other elements of the space transportation and operations systems. During this task and at other points in the efforts, liaison was maintained with the spacecraft study contractors through NASA MSFC. This was done for the purpose of exchange-

ing information as to payload requirements on the spacecraft and restrictions on the payloads due to weight, power, and volume envelopes.

Costing information was to be developed in task 5. For each of the payload concepts in task 4 recurring costs were to be developed for individual payload packages and for the assembled payload as a whole. In addition, the contractors were to develop qualitative descriptions and rough order-of-magnitude estimates of the ground segment costs associated with each system. Cost drivers were to be identified and the cost sensitivity of these drivers estimated.

Next, for each payload concept defined in task 4, enabling and supporting technologies critical to its eventual implementation and operation were to be identified and ranked in task 6. Technology development scenarios required to reduce technical and economic risks to the level of normal commercial risk were also to be ranked.

Finally, in task 7 the contractors were to compare the payloads resulting from task 4. The comparisons were to include a description of each payload's advantages and disadvantages.

As mentioned earlier, NASA imposed a number of baseline conditions for the performance of these tasks. A general guideline was that 1998 operational technology be used in developing the concepts. There was to be no in-orbit payload assembly, but mating of spacecraft to orbit transfer vehicles, payload checkout and calibration, and other orbital procedures were not ruled out. These particular constraints were imposed because when the contracts were written, the space station program was not a certainty. The facilities were to have a minimum lifetime of 10 years without servicing. Baseline conditions for service aggregation scenarios and payload concepts included coverage up to and including CONUS only, domestic FSS or DBS only, and to C-, Ku-, and Ka-band frequencies only. In the "variations" cases, service coverage could be broadened to include the entire Western Hemisphere. Services could be expanded to include, but not be limited to, mobile and data collection and frequency bands in addition to the C, Ku, and Ka bands, and intersatellite link capabilities to international or other domestic satellites could be added. Finally, two launch concepts were mentioned earlier as providing constraints on the task 4 definition efforts. The first was that the combined spacecraft and upper stage be launched on a single shuttle and that the spacecraft (including payload) weigh no more than 12 000 lb. The second launch concept allowed a spacecraft alone (without upper stage) to use the full shuttle launch capability (65 000 lb).

In addition to these baseline conditions, NASA suggested a number of evaluation criteria:

- (1) Task 2: Service aggregation scenarios
 - (a) Potential communications capacity from an orbital slot
 - (b) Effects on both space and terrestrial plant in place
 - (c) Communications service reliability and availability
- (2) Task 3: Payload concept development
 - (a) Frequency spectrum utilization
 - (b) Communications capacity of orbital slot
 - (c) Intersystem interference
 - (d) Communications service reliability and availability

- (e) Growth potential and flexibility
- (f) Complexity
- (g) Percentage of payload capacity utilization

INITIALIZATION AND DATA BASE DEVELOPMENT

The initial portion of these studies consisted of developing a data base that would support the development of the service aggregation scenarios and subsequent payload concepts and be used in the other tasks of the effort. The data base included the following major components:

- (1) Forecasts of satellite traffic (voice, video, data, DBS, and mobile)
 - (a) U.S. domestic
 - (b) Foreign domestic within ITU Region 2
 - (c) Within ITU Region 2
 - (d) International: Region 2 to Europe/Africa (Atlantic Ocean Region, or AOR) and Asia (Pacific Ocean Region, or POR)
- (2) Models of satellite traffic distribution
- (3) Estimates of future space and terrestrial plant in place
 - (a) Number of satellites by frequency band
 - (b) Satellite capacity
 - (c) Satellite location
 - (d) Number of ground terminals by frequency band
- (4) Forecasts of satellite communications technology
- (5) Estimates of the status of in-orbit payload servicing technology for low-Earth-orbit (LEO) and GEO operations
- (6) Determination of appropriate costing methodologies for communications components to be used in estimating payload costs

The data bases developed are extensive and thus difficult to summarize in this report. The details are available in the contractor reports (refs. 1 and 2).

SERVICE AGGREGATION SCENARIOS

In this phase of the effort the contractors developed a variety of communications service aggregation scenarios. These groupings of services met the various selection criteria described earlier and satisfied the conditions set forth by NASA.

The scenarios represent the heart of the studies, as they are the basis on which the payload concepts were developed for a large-scale, turn-of-the-century geostationary facility. The following major components were developed for each scenario:

- (1) Traffic model served
 - (a) Area covered by service and frequency
 - (b) Capacity for each service by frequency
 - (c) Percentage of the forecast markets addressed

- (2) Advantages and disadvantages
- (3) Desirability relative to other scenarios

FACC developed 8, and RCA 10, scenarios. These were ranked by each contractor and the results presented to NASA Lewis. NASA Lewis then selected, with modifications, several scenarios for more detailed development.

Ford Aerospace and Communications Corporation

The eight service aggregation scenarios developed by FACC are as follows:

- (1) Scenario I: High-capacity C- and Ku-band FSS and Ka-band CPS capability
- (2) Scenario II: Medium-capacity CONUS FSS and medium-power DBS capability
- (3) Scenario III: Medium-capacity CONUS LMSS capability
- (4) Scenario IV: High-capacity medium- and high-power video distribution and DBS capability
- (5) Scenario V: High-capacity CONUS FSS and LMSS trunking and CPS capability
- (6) Scenario VI-A: High-capacity half-CONUS FSS, Region 2 international, ISL to central/western CONUS and "European" platforms, and Western Atlantic maritime services
- (7) Scenario VI-B: High-capacity half-CONUS FSS, Region 2 international, ISL to central/eastern CONUS and "East Asian" platforms, and Eastern Pacific maritime services
- (8) Scenario VII: High-capacity intra- and inter-Region 2² FSS, ISL's for European and Asian international traffic, and Region 2 DBS services

These scenarios are described briefly in table 3.

FACC ranked the scenarios against a number of equally weighted criteria:

- (1) Optimum communications capacity from an orbital position
- (2) High growth markets
- (3) Effect on terrestrial and space plant in place
- (4) Technical feasibility of service grouping
- (5) Service to CONUS FSS first and then also add international; service to Region 2 international and domestic
- (6) Communications service reliability and availability
 - (a) Risk ("all the eggs in one basket?")
 - (b) Numerical reliability

²Inter-Region 2 is used to mean between Region 2 and Regions 1 and 3.

- (c) Frequency selection for availability
- (7) Institutional issues
 - (a) Antitrust issues
 - (b) Regulatory issues (FCC, ITU, etc.)
 - (c) Insurance issues
 - (d) Ownership and financing issues
- (8) Multipayload schedule risk
- (9) Privacy issues
- (10) National security and pride
- (11) Restriction on reallocation of existing service
- (12) Orbit servicing outages during GEO servicing

The result of this ranking is included in table 3.

When the scenarios and their rankings were presented to NASA Lewis, scenarios II, IV, V (without the mobile services), and VI-A and VI-B (complementary scenarios) were selected. Several factors were considered by NASA Lewis in making the selection: the scenario rankings, the service aggregations put forth by the other contractor (RCA), and a desire to have a number of different baseline and variation scenarios.

RCA Astro-Electronics Division

The 10 service aggregation concepts developed by RCA are summarized in table 4 and presented briefly here:

- (1) Concept 1: High-capacity (addressing 20 percent of projected traffic) CONUS FSS trunking and CPS utilizing C, Ku, and Ka bands
- (2) Concept 2: Medium-capacity (addressing 13 percent of projected traffic) CONUS FSS utilizing C, Ku, and Ka bands
- (3) Concept 3: Same as concept 2 plus video distribution (addressing 10 percent of projected video traffic)
- (4) Concept 4: LMSS addressing 100 percent of CONUS and Canadian demand for voice and digital services through UHF and L band.
- (5) Concept 5: High-capacity CONUS FSS of concept 1 plus ISL capability (through W band or optical link) for Americas-to-Europe/Africa and Americas-to-Asia traffic, plus data distribution capability consistent with the TDAS
- (6) Concept 6: High-capacity CONUS FSS of concept 1 combined with the LMSS capability of concept 4
- (7) Concept 7: High-capacity DBS and broadcast video distribution for CONUS (addressing 50 percent of projected market for each service)
- (8) Concept 8: High-capacity FSS and ISL capabilities of concept 5 combined with 100-percent FSS capability for Canada, Central America, and South America

(9) Concept 9: High-capacity (50 percent of market) CONUS DBS

(10) Concept 10: Medium-capacity (25 percent) CONUS and high-capacity (50 percent) Central America and South America broadcast television distribution and DBS

The following issues were considered by RCA in both developing and ranking the scenarios:

(1) Is the platform capacity consistent with realistic forecast demand per orbital slot? (How big?)

(2) Is there a clear advantage over nonaggregated satellites? (Why aggregate?) For example,

(a) Is the satellite capacity inadequate?

(b) Would the potential platform system (space and ground segment) result in a cost savings?

(c) Would there be improved connectivity?

(3) Is there an acceptable level of risk? (Can it be done?)

(a) Institutional

(b) Technological

(4) Is the effect on ground-segment plant in place minimal? (What about the sizable investments already made or committed?)

RCA, with NASA approval, selected FSS baseline concepts 1 and 3 and variation concepts 4 and 5 for further development. In subsequent sections of this report the LMSS concept (concept 4) is referred to as concept 1; the FSS 20-percent concept (concept 1), as concept 2; the FSS 13-percent concept (concept 2), as concept 3; and the FSS/ISL/TDAS concept (concept 5), as concept 4.

PAYLOAD CONCEPT DEVELOPMENT AND DEFINITION

FACC developed five, and RCA four, viable payload concept descriptions and communications system architectures based on the scenarios selected in the previous phase of the effort. These concepts and architectures were ranked for further, more detailed development by the contractors, with NASA reviewing the rankings. Payload concepts, including the general physical configuration, were then developed to the subsystem block diagram level. The communications system architecture descriptions included antenna coverage and patterns, frequency plans, modulation schemes, access methods, and connectivity arrangements. The detailed definition of the payload concepts included descriptions of the following:

(1) Transponders (number, frequency, burst rate, etc.)

(2) Antennas (type, diameter, gain, etc.)

(3) Switches (configuration, processing, etc.)

(4) Design sketches (stowed and deployed)

(5) Subsystem level block diagrams (amplifiers, receivers, etc.)

Besides this definition of the payload concepts and corresponding technical characteristics, FACC and RCA also defined the payload requirements on the spacecraft. These requirements included

- (1) Overall weight
- (2) Attitude control
- (3) Overall power
- (4) Stationkeeping
- (5) Overall dimensions

- (6) Thermal control
 - (a) Lifetime
 - (b) Power conditioning
 - (c) Eclipse capability

A dialog was maintained through MSFC with the MSFC bus contractors in order to exchange the requirements and constraints information and other payload and bus interface data.

In addition to defining payload concepts and technical characteristics, the contractors described the effect of in-orbit payload servicing technology on the payload characteristics and on the payload requirements for the bus, transportation, and space operations systems. The in-orbit servicing categories examined were, for the payload only: deployment, checkout, repair, refurbishment, and reconfiguration.

Ford Aerospace and Communications Corporation

Basically the FACC payload design objective was to maximize the capacity of an orbital slot while minimizing the cost per revenue-producing circuit. The aggregation scenarios from the previous phase were quantified in terms of bandwidth requirements. Payload concepts were then derived to satisfy those requirements by applying frequency reuse, traffic balancing, maximization of fill factors, onboard processing, and tailoring of equipment quantities to traffic volumes. The traffic distributions and volumes used were those developed in the first phase of the contract effort.

NASA-selected concepts were then defined to the component level by using a top-down system engineering approach along with multilevel tradeoff analyses and iterations. Some of the results of these efforts are given in figures 1 to 30 and table 5. These results are grouped by scenario, or payload concept, with the following information given for each concept:

- (1) Services allocation overview
- (2) Scenario block diagram overview
- (3) Payload block diagram overview
- (4) Antenna configuration

The concepts developed provide high capacities from a single orbital slot because they are optimized relative to the assumed traffic distributions and to higher utilization and frequency reuse.

Figures 1 and 2 and table 5 provide an overview of FACC scenario II and its service allocations. This scenario includes medium-capacity CONUS (including Alaska, Hawaii, and Puerto Rico) FSS and medium-power DBS payloads. It is basically a transitional satellite, where the C-band payload (fig. 3) is the current conventional one consisting of twenty-four 36-MHz transponders and a single CONUS beam. The Ku-band FSS payload (fig. 4) has twenty-four 54-MHz transponders and three-beam coverage: CONUS, east CONUS, and west CONUS. Overflow traffic can be routed from the east and west beams to the full CONUS beam through a radiofrequency (RF) switching matrix. The high-capacity Ka-band payload, which is unconventional as compared with current communications satellite configurations, provides both fixed (fig. 5) and scanning beam (fig. 6) FSS coverage. Twenty fixed beams furnish trunking service to the 20 largest metropolitan areas, and six regional scanning beams provide CPS and thin-route service. The fixed and scanning Ka systems are interconnected. An onboard baseband processor (fig. 7) routes the channels in the scan system. An introductory-level Ku-band medium-power (100 W/channel) DBS service (fig. 8) is provided through essentially two half-CONUS beams of eight channels each. The DBS payload severely limits the possible location of the satellite for regulatory reasons: currently only 101° and 110° W longitude would be suitable. This aggregation of payloads was earlier referred to as being transitional. To effectively use the TDMA Ka-band system, the traffic would have to be approximately 87 percent digital. However, only 60 to 70 percent digital traffic is projected for the timeframe of interest. Hence the main utility of this scenario would be as a transition to some later configuration. Scenario II has the lowest capacity of the scenarios selected for detailed development.

Scenario IV is a Ku-band broadcast video scenario, with high-capacity, high-power (200 W/channel) DBS and medium-power (50 W/channel) FSS channels. An overview of this scenario is given in figures 9 and 10 and table 5. The high-power DBS is provided through sixty-four 24-MHz channels, sixteen in each of four time-zone beams. The current design of the medium-power payload at Ku FSS has sixteen 24-MHz channels in each of three beams: CONUS, east CONUS, and west CONUS. Half the FSS channels in each beam are interconnected with the DBS channels by eight 7-by-7 switching matrices. A block diagram of both payloads is presented in figure 11. The high-power requirements of the direct-to-home portion of the payload bring the overall power requirements to about 35 kW, the highest of the scenarios selected for further study. Also, the DBS nature of the scenario limits the possible orbital locations of this satellite to 101° and 110° W for regulatory reasons, as was the case for scenario II.

Figures 12 and 13 and table 5 summarize scenario V. The scenario in a sense is a higher capacity version of scenario II without the DBS payload package. It has a high-capacity CONUS FSS payload designed to meet the distributional characteristics of CONUS traffic. The C- and Ku-band payloads are basically for analog voice trunking; the Ka-band payload is the same all-digital TDMA system as in scenario II (figs. 5 and 6). C-band capacity has been doubled over that in scenario II by using three beams to cover CONUS and a fourth to double the reuse in the northeast corner of CONUS (fig. 12). Similarly, the capacity of the scenario V Ku-band payload triples that of scenario II by using nine beams: eight to cover CONUS and the ninth to double the reuse in the New York/New Jersey area. All the C-band channels are interconnected through onboard switching, as are all the Ku-band channels (figs. 14 and 15). Although scenario II required about 87-percent digital traffic for efficient implementation, scenario V has been optimized to 68 percent, roughly that forecast for

the timeframe of interest. Seven scenario V satellites or platforms could accommodate all the year 2008 projected CONUS FSS traffic (including spare capacity).

The remaining two scenarios selected for further development are basically complementary. They use intersatellite links to communicate between themselves and European and Asian platforms. The pair is designed to handle all the ITU Region 2 Intelsat traffic and all the intra-Region 2 traffic and to provide all domestic coverages for non-CONUS Region 2. The traffic types and areas served are as follows:

(1) Scenario VI-A

- (a) United States (domestic, regional, and international)
- (b) Latin America and the Caribbean (regional and international)
- (c) Intersatellite links (European platform and scenario VI-B)
- (d) Other (Western Atlantic maritime)

(2) Scenario VI-B

- (a) United States (domestic)
- (b) Canada (domestic, regional, and International)
- (c) Latin America and Caribbean (domestic)
- (d) Intersatellite links (Asian platform and scenario VI-A)
- (e) Other (Eastern Pacific maritime)

An overview of scenario VI-A is provided in figures 16 and 17 and table 5, and one of scenario VI-B in figures 24 and 25 and table 5.

Scenario VI-A (fig. 16) provides CONUS coverage with the same payloads as in scenario V. In addition to these payloads, a nine-beam, 12-channels-per-beam C-band regional and international payload covers all the Intelsat gateway stations for Central and South America and the Caribbean. A block diagram of the payload is shown in figure 18. One feature of this payload is the inclusion of onboard baseband processing, in particular A/D and D/A conversion of uplinked analog frequency-division multiple access (FDMA) signals for routing purposes. Block diagrams are shown in figures 19 to 21. A Western Atlantic maritime payload package (fig. 22) provides 125 L- and C-band circuits for ship-to-shore and shore-to-ship traffic. Finally, the payload has two intersatellite links, each with 1.5-Gb/s capacity (fig. 23). One link is nominally to a European platform and the other to scenario VI-A's complement, scenario VI-B. Scenario VI-A, the highest capacity scenario considered, is so large that it must be assembled and mated to an orbit transfer vehicle in orbit.

Scenario VI-B, located to the west of scenario VI-A, handles Canadian Intelsat traffic, Region 2 domestic non-CONUS traffic, and Eastern Pacific maritime traffic. CONUS is covered by Ku- and Ka-band high-capacity FSS payloads as in scenario V (the C-band CONUS package could not be used as it could not be isolated from the Canadian and Mexican C-band service). Finally, scenario VI-B can be interconnected with an "Asian" platform to the west and with scenario VI-A to the east through ISL's. The various coverages are shown in figures 24 and 25, block diagrams of the various domestic and regional payloads in figures 26 to 28. For non-CONUS coverage Canada has three C-band beams; Mexico, two; Central America and the Caribbean, one; and South America, three. Ku-band coverage is provided to Mexico and South America and to the Toronto-Montreal area of Canada. In the Canadian system three channels in each beam are processed onboard (fig. 29) for routing Intelsat traffic to the ISL's.

The Eastern Pacific maritime payload (fig. 30) is identical to that of scenario VI-A. Like scenario VI-A, scenario VI-B is large enough to require orbital assembly.

Both scenarios VI-A and VI-B pose significant institutional and regulatory issues regarding ownership, operation, insurance, and the like. However, an 11-satellite network consisting of two scenario VI-A satellites, and two scenario VI-B satellites, three scenario IV (video distribution) satellites, three scenario V (CONUS FSS) satellites, and a mobile services satellite could meet essentially all the Region 2 requirements estimated for the year 2008. Table 6 and figure 31 describe this constellation.

In addressing the effect of on-orbit servicing technology, FACC did not perform detailed analyses. They assumed that a modular payload would facilitate in-orbit servicing and repair and pointed out that designing for such modularity would affect both the cost and the weight of the payloads. Though noted, effects on the bus and the costs of the servicing system were not examined.

The limited FACC review of the servicing question suggested that LEO servicing for facility fueling and the mating of space-based transfer stages were the most beneficial possibilities in on-orbit servicing for the mid to late 1990's. LEO repair of failed components before the facility is transferred to GEO may also have possibilities. FACC thought GEO servicing would not be available for the timeframe of interest. In the case of either LEO or GEO servicing, it was stressed that the economics needed to be thoroughly assessed.

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RCA based their concept development on the introduction of platforms in about the year 2000 after an evolutionary process driven by the inability of conventional satellites to accommodate the increasing traffic demand forecast. Their rationale for determining the capacity requirements and subsequent payload definition of the selected platforms, particularly for the fixed-service scenarios, was based on several factors as they would pertain to the strategies of a satellite communications market leader who would develop a platform. These factors include addressable market size, platform operator's market share, satellite fill factor, demand growth rate, platform life, and number of orbital slots authorized for use by the satellite operator. A complete description of the platform capacity development process is available in the RCA report. A summary of the description of the RCA payload concepts follows. Descriptions similar to the FACC concepts are presented in figures 32 to 47 and table 7.

The LMSS concept, concept 1, consists of a single, second-generation land mobile platform sized for an end-of-life demand for the year 2008 that provides voice service at UHF and digital data service at L band to the United States and Canada. (Subsequent to the completion of this contract, the FCC ruled to limit landmobile frequencies to L band only.) Figure 32 depicts the LMSS network configuration, which links (1) the spacecraft and the mobile user and (2) the spacecraft and a gateway connected to the public switched telephone network. This concept would require a single orbital slot, and thus it offers a potential advantage over a multiple-satellite system by reducing the mobile terminal antenna requirements from a steerable antenna to a fixed antenna. The

LMSS scenario is summarized in figure 33, and a block diagram of the concept is shown in figure 34. The mobile radiotelephone service uses amplitude-companded, single-sideband modulation and has transponders of 1-MHz bandwidth and a coverage pattern that permits a frequency reuse of 7.9 times. The digital data service for paging and dispatch uses frequency-shift keying modulation and has a transponder bandwidth of 160 kHz and a coverage scheme that results in a frequency reuse of 1.1 times.

The beam widths required per service can be satisfied by using a single 30-m-diameter antenna with a 20-m-diameter L-band screen superimposed on a 30-m-diameter UHF reflective screen. The proposed antenna configuration is described in table 7.

Concept 2 provides high-capacity FSS (20 percent of the 1998 trunking plus CPS demand - 466 transponders) to CONUS (fig. 35). As shown, the concept is characterized by spot beam coverage to major cities and by Ka-band scanning beam coverage to other areas of CONUS. Extensive frequency reuse (C band, 9.1 times; Ku band, 6.3 times; and Ka band, 5.4 times) results from this spot beam approach. A major component of the payload that enables this coverage is a 10.5-m-diameter unfurlable C-band antenna. The CONUS coverage per frequency band is illustrated in detail in figures 36 and 37.

All three bands are interconnected by a baseband processor consisting of 200 60-Mb/s channels and several IF time-division multiple access (TDMA) switches. A 36-MHz channel bandwidth was selected as the system standard. Dedicated wideband (Ka band) channels are established that bypass the switching matrix for certain beam (city) pairs where sufficient traffic exists. A block diagram (fig. 38) for this payload concept illustrates the switching and processing architecture.

The antenna systems required for the various coverages and services are listed in table 7. The antenna system weighs 332 kg with antennas ranging from a 10.5-m-diameter C-band unfurlable antenna to a 1.5-m-diameter deployable Ku-band antenna.

The concept 3 scenario carries 13 percent of the market share of FSS traffic and 10 percent of the forecast video distribution traffic. This platform would have 303 transponders for trunking and CPS services plus 10 transponders for video distribution. As in concept 2 a channelized design with a 36-MHz transponder bandwidth has been selected and the C, Ku, and Ka bands are interconnected. The services provided by this concept and some of the characteristics of the payload are shown in figure 39.

The reduction in capacity requirements and the addition of video distribution services reduced the need for spot beam coverage in the C and Ku frequency bands. The CONUS coverage by frequency band is illustrated in detail in figures 40 to 42. CONUS coverage by C band results in a 2.0-times frequency reuse, and quarter-CONUS Ku-band beams allow 3.4-times frequency reuse. The Ka-band system is similar to that of concept 2 as it includes spot beams for the major traffic centers and scanning beams for other areas.

The switching and interconnectivity scheme, which is similar to that of concept 2, is shown in figure 43. The capacity requirements have obviously been reduced for the baseband processors and IF TDMA switches.

The antenna subsystems are listed in table 7. The total weight of these subsystems is 208 kg.

Concept 4, the FSS/ISL/TDAS concept, combines the FSS payload (20-percent capacity) of concept 2, an intersatellite link payload, and a tracking and data acquisition system (TDAS) payload. The ISL payload connects CONUS to the platform and to the international satellites serving the Europe/Africa and the Far East/Pacific regions. The TDAS payload is independent of the other payloads but shares the FSS Ka-band and Ku-band antenna reflectors. Additional transponders on the FSS payload accommodate the ISL capacity. Thus there is also an increase in the TDMA switch and baseband processor capacity. The concept 4 scenario is summarized in figure 44.

The Ku- and Ka-band coverages shown in figures 45 and 46 are similar to those of concept 2 except that there is an additional Ku-band spot beam on White Sands for TDAS connectivity and an additional Ka-band spot beam on Denver. The C-band coverage is the same as in figure 37. The platform would meet 100 percent of the requirements for international traffic between the United States and Europe/Africa and the Far East/Pacific regions. The ISL can operate at W band (60 GHz) or as an optical link. For this study W band was selected and is thus used for the weight and power estimates, the antennas, etc.

The TDAS payload connects user spacecraft and five user sites in CONUS. White Sands is linked by Ku band and the other sites are linked by Ka band. The links to the user satellites are by S, Ku, and W bands. The TDAS link to another TDAS satellite, which would provide global coverage, could be accomplished by W band or an optical link.

The payload interconnectivity using a baseband processor and IF TDMA switches is shown in block diagram form in figure 47. Also, the antennas for the FSS component of this concept are the same as those for concept 2 (table 7). The additional antennas required for the ISL links are two W-band 3.0-m-diameter antennas. The TDAS payload requires one W-band, TDAS crosslink, 2-m-diameter antenna; five W-band, 1-m-diameter user antennas; two Ku-band, 4-m-diameter user antennas; an S-band user antenna array; and an added Ku-band horn for the White Sands link.

The payload concepts were evaluated (not quantitatively in terms of cost and weight) for the effect of servicing on design. The platform servicing functions that appear to be technically feasible and potentially cost effective are as follows:

- (1) Large-Structure Assembly and Deployment
 - (a) Manual assembly and deployment of large antennas and arrays
 - (b) External mounting of transfer propulsion system
- (2) Pretransfer checkout and assembly at low Earth orbit (LEO)
 - (a) Antenna pattern measurements and adjustments
 - (b) Removal of auxiliary launch support structure
 - (c) Loading of liquid fuel
 - (d) Removal of protective covers
 - (e) Servicing of thermal blankets
 - (f) Repair of pretransfer failures

- (3) Remote platform servicing at geosynchronous Earth orbit (GEO)
 - (a) Fueling and refueling
 - (b) Module replacement
 - (c) Payload modification and updates

The effects of LEO servicing would be in terms of assembly mechanisms, development of interfaces for test and calibration, and development of a low-thrust booster for moving a deployed platform from LEO to GEO. Payload design considerations for payload servicing at GEO include built-in test equipment for fault detection and isolation, servicer docking capability, module replacement capability, and the ability to check, test, and calibrate replacement modules. Servicing could probably simplify deployment design considerations, enable deployment of large structures, reduce the risk of failure before operational status is achieved, and lengthen platform lifetimes.

CRITICAL TECHNOLOGY

The contractors identified both enabling and supporting technologies critical to the eventual implementation of the defined payloads. Earlier sections have shown that the payload concepts developed by the contractors differed, if not in the services provided, then in the way they were provided. Contractor perceptions of critical technology needs or rankings of needs differed accordingly.

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FACC's key technology drivers were as follows:

- (1) Baseband processing
 - (a) High-efficiency modulation/demodulation
 - (b) A/D format conversion
 - (c) High-speed programmable frequency source
 - (d) Scanning and processing algorithms
- (2) Antennas
 - (a) Dynamic beam
 - (b) Polarization tracking at Ka band for horizontal and vertical reuse
 - (c) Dual polarizer for receiving and transmitting bands
- (3) Transponder
 - (a) High-power Ku- and Ka-band SSPA's
 - (b) High-speed switching at 11 and 20 GHz
 - (c) Dielectric resonator filters and oscillators
- (4) Intersatellite links
 - (a) Optical
 - (b) RF
- (5) Support technology
 - (a) Materials technology
 - (b) Monolithic microwave integrated circuit (MMIC) and very large-scale integration (VLSI) development

- (c) Device development: gallium arsenide (GaAs), complementary metal oxide semiconductor - silicon on sapphire (CMOS-SOS), etc.
- (d) Radiation-hardening development
- (6) Transportation and space station support
 - (a) Deployment
 - (b) Assembly
 - (c) Alignment
 - (d) Servicing
 - (e) Checkout at LEO
 - (f) Transportation to GEO

Of the items on this list, six were identified as major new component drivers. These are, in FACC's ranking,

- (1) Polarization tracking at Ka band
- (2) High-speed programmable frequency source
- (3) Baseband processing with high-efficiency modulation/demodulation
- (4) ISL's
- (5) A/D format conversion
- (6) Dual polarizers for both receiving and transmitting bands

The highest payoff technology item identified is the development of a polarization variation tracking methodology at Ka band to allow full reuse of the Ka-band frequencies in high-density trunking areas (e.g., New York, Chicago, and Detroit). The technique would track the polarization phase disturbed by rain or other atmospheric causes and would realign the antenna polarization with the received signal to maintain the necessary cross-polarization isolation between the orthogonal signals.

The next highest payoff technologically is a programmable frequency shifter as an alternative to a significantly expanded baseband processor. These shifters would allow switching at a packet level in an satellite-switched TDMA architecture. This allows switching on a TDMA basis and routing without demodulation and remodulation to a circuit level.

The third ranked critical technology is baseband processing with high-efficiency modulation/demodulation. A baseband processor is needed to service the small and direct-to-user applications in the FACC scenarios. The capacity required ranges up to 9.0 Gb/s, about three times the planned capacity of the NASA Advanced Technology Communications Satellite (ACTS) processor. High-efficiency modulators and demodulators are also needed.

Intersatellite links, are next in the ranking. RF links appear adequate for near-term capacity requirements of 1.5 to 2.0 Gb/s, but optical links will be needed for growth to higher capacities. Other advantages of laser ISL's are interference immunity and smaller apertures. Without the ISL's the FACC scenarios VI-A and VI-B would not be interconnected with each other or with Atlantic Ocean Region and Pacific Ocean Region satellites. The ability to eliminate double-hop transmission through the use of an ISL also contributes to making ISL's a high-payoff technology item.

The fifth ranked technology is A/D format conversion. Required here are high-speed converters to provide onboard format conversion from frequency division multiplexing/frequency modulation (FDM/FM) to digital to allow onboard

switching and routing at a packet level while still accommodating the existing analog ground plant in place.

Finally, the development of dual polarizers for right or left-hand circular polarization for both receiving and transmitting is desirable to allow the use of a single large reflector rather than two reflectors.

The applicability of these critical technologies to the FACC payload scenarios is shown in table 8. Additional details regarding needed technology are given in the FACC final report.

FACC also indicated a number of support technology areas that cut across these developments and others as well:

- (1) Device processing (CMOS-SOS, etc.)
- (2) Discrete (GaAs) power amplifiers, receivers, etc.
- (3) MMIC (RF components)
- (4) VLSI (digital components)
- (5) Materials technology (dielectric resonating oscillators, structural, etc.)
- (6) Optical (interconnects, switching, etc.)
- (7) Radiation hardening (for long life)
- (8) Use of space station and associated capabilities

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The critical technologies developed by RCA for enablement of the payload concepts are listed in table 9. The technologies are characterized in terms of technical risk and cost uncertainty according to the current state of the art. The concepts associated with the technologies are also identified.

Antennas are rated as having the highest combined technical risk and associated cost uncertainty, especially the 30-m-diameter UHF/L-band antenna for the mobile concept. The feed array associated with the proposed design must include the feed elements, the beam-forming network, the power amplifiers, the low-noise receivers, the diplexer, and the thermal control systems. Material and construction techniques that will provide stable RF performance over temperature are required. Appropriate unfurling techniques must also be refined. Other advancements in antenna technology such as material and construction techniques to reduce root-mean-square surface error and improved pointing are required for the Ka-band antennas, the 10.5-m-diameter C-band antenna and the W-band antenna.

Baseband processor requirements were determined for each of the payload concepts in terms of modulators/demodulators, memory, error correction encoders/decoders, and the baseband switching matrix. Key parameters, for example, include requirements for eight phase shift key (PSK) modulators/demodulators operating at 120 Mb/s for concept 2 and 400 Mb/s for the ISL links of concept 4.

Concepts 2, 3, and 4 require 12-by-12 and 25-by-25 IF switch matrices operating at a 36-MHz bandwidth. They also require 50-ns switching times and 2-dB peak-to-peak insertion loss variation. RCA suggests that these switch matrices be based on the use of field-effect transistor (FET) devices. MMIC technology with a GaAs substrate material would be used.

Concept 4 uses ISL's from the TDAS payload to other GEO and LEO payloads and from the FSS trunking payload to Atlantic Ocean Region and Pacific Ocean Region international satellites. The ISL's can be operated at either optical frequencies or W band (60 GHz). The greatest uncertainty for implementation of W band is the availability of the traveling wave tube amplifiers (TWTAs) at 25 W. Most of the optical components such as lasers, tracking modulators/demodulators, multiplexers, and FEC's require further development.

RCA selected solid-state, high-power amplifiers (SSPA's) to provide the amplifier functions for the C, Ku, and Ka bands. Part of the rationale for choosing SSPA's is that 36 MHz has been chosen for the common channel bandwidth for facilitating interconnection among the three bands. Consequently there is not as great a need for high power levels to ensure satisfactory link performance when wideband channels are used, especially at Ka band. Concept 2 requires a 60-W Ku-band SSPA. RCA has tested breadboard 40-W Ku-band SSPA's, but further development in this field is required.

The RCA final report gives detailed information pertaining to each critical technology. The details, for each technology, include critical areas, potential problems, characteristics required, and development scenarios.

COSTING

The contractors estimated recurring costs (in constant 1984 dollars) for individual payload components and for each assembled payload as a whole. In addition, they made rough order-of-magnitude cost estimates of the ground segment associated with each payload concept. As explained later, the approaches taken to this effort by the contractors were somewhat different.

Additional cost information was developed by both contractors as part of their efforts to compare platform and nonplatform systems. This additional information is summarized in the section "Discussion of Findings."

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Basically the FACC approach utilized the PRICE H (ref. 15) costing model. PRICE (Parametric Review of Information for Costing and Evaluation) is a computerized model for estimating the costs of electromechanical hardware assemblies and systems. The model was developed by RCA and has been used at FACC to estimate space system costs. It will not be further described here other than to note that the model allows for consideration of technological improvements and for component/system complexity.

FACC calibrated and validated the PRICE H model by using component and system quantity, weight, volume, cost, etc., from actual C- and Ku-band transponder and antenna systems built by FACC. Results were then applied to the equivalent frequency band components and systems of each scenario. As there were no comparable real-world data for calibrating the model for Ka-band components and systems, FACC estimated the complexity of Ka- relative to Ku-band equipment. They then compared the resultant PRICE H output with engineering estimates to determine if the output was reasonable.

The FACC report contains detailed PRICE H cost estimates for each payload and its components. A summary of these costs is presented in table 10. Earth terminal cost estimates are presented in table 11. Actual ground terminal costs depend on a variety of factors, such as the location and the type of modulation and access. FACC assumed that C-band systems would remain primarily analog and that Ku- and Ka-band systems would be digital, with TDMA used at Ka band. FACC compared a ground terminal associated with scenario V platforms and one with an equivalent conventional satellite system as part of Task 7, System Comparison. This comparison is discussed later.

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The payload costs developed by RCA are defined as the first-unit, recurring cost to manufacture and exclude development cost, profit or fee, general and administrative costs, and launch costs. RCA used two cost modeling approaches independently to estimate the platform payload costs. This dual approach was taken to bound the uncertainty inherent in the costing of advanced concepts and thus produces a more realistic set of cost data. One approach, the RCA Heritage Model, draws on a well-defined data base accumulated for 5 yr of satellite design and manufacture at RCA Astro. Some of the components of this model are a labor-mix analysis, actual engineering and manufacturing person-months expended, material cost, and considerations of the operational components, such as the mass of a particular payload or spacecraft. The output of the model can be modified to compensate for cost effects related to complexity and development uncertainties. This RCA model is proprietary.

The other cost-estimating approach used in the study is based on the SAMSO-5 model. This model uses subsystem masses and the beginning-of-life power of the spacecraft to estimate the antenna subsystem, payload electronics, and other subsystem costs. Its cost-estimating relationships were developed by performing regression analyses on cost data for many spacecraft programs including military, NASA, and commercial programs. Since the SAMSO-5 model is based on historical costs, some adjustments had to be made to account for advanced technology. These adjustments were applied to the Ka- and Ku-band antennas, the large unfurlable reflectors, and the onboard processors.

The recurring communications platform payload costs in 1984 dollars for the four RCA concepts are summarized in table 12. The costs represent the average of the results obtained from the two modeling approaches. The results from these two approaches were within 15 percent of each other for concept 1 and within a few percent for the three FSS scenarios. The payload costs ranged from \$120 million for the 1172-kg LMSS payload to \$321 million for the 3155-kg FSS/ISL/TDAS payload. Table 12 also shows the cost per active transponder channel per payload. These transponder channel costs are 10 to 35 percent less than those for current RCA C- and Ku-band satellite transponders. RCA notes that the use of TWTAs rather than SSPAs accounts for much of the higher cost associated with the current Ku-band satellites.

The RCA report gives cost estimates for the antenna and transponder components for each payload concept.

RCA developed "quantitative differential" cost estimates for each concept's associated ground terminal to use in assessing the economic merits relative to a nonplatform approach. Differential thus refers to equipment that is different for platform and nonplatform concepts. The ground terminal costs differed because additional antennas and the associated low-noise amplifier (LNA) were needed in the nonplatform approach to provide the same interconnectivity as the platform approach did. Common equipment such as multiplexers and modulation and frequency converters were not considered since it was assumed that the same total traffic would be addressed by both the platform and nonplatform approaches. Table 13 includes the pertinent antenna and LNA costs. The LNA noise figures assumed for costing purposes were 0.75 and 3 dB for C- and Ka-band trunking stations and 2 and 4 dB for Ku- and Ka-band CPS stations.

SYSTEM COMPARISONS

The contractors each compared the payload concepts developed in the previous tasks and evaluated the benefits, advantages, and disadvantages of each concept. The comparisons were made on the basis of spectrum utilization, cost, associated ground segments, and other factors. In addition, the contractors discussed the probability of implementing each payload.

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Weight and power. - The weight and power requirements of each payload concept have been stated earlier. Table 14, however, brings these parameters together for ease of comparison. The top half of table 14 displays the payload characteristics that would result if projected (high risk) technology were used; the bottom half shows those that would result if emerging (low risk) technology were used. As could be expected, using low-risk technology results in heavier, more power-consumptive payloads. Use of low-risk technology would result in scenario V, and possibly scenario II, exceeding single-shuttle capability without fuel servicing or augmented perigee boost. Using high-risk technology would result in lower payload weight, putting scenario V in the range of a single shuttle launch. Scenarios VI-A and VI-B both require a dual launch.

Spectrum/orbit utilization. - FACC examined spectrum/orbit utilization in terms of bandwidth and reuse, modulation efficiency, and throughput. Frequency reuse achieved by each payload is shown in table 15. The range is from 2 to 4 times for C band (CONUS), 3 to 9 times for Ku band, and 5.8 to 12 times for Ka band. Modulation efficiencies assumed for the payloads are shown in table 16. Maximum throughput is shown in table 17 for four of the five scenarios. Scenario IV is a video distribution satellite and throughput is not a good measure for video.

Space segment costs. - The costs of the payload concepts were compared in the previous main section. However, in order to compare a platform payload concept against alternative ways to deliver the same services (i.e., by using multiple satellites), FACC developed a total space segment cost. The assumptions used in arriving at such costs are given in table 18, and the costs themselves in table 19. These costs were then further converted to cost per 36 MHz, or cost per transponder, per year as shown in table 20. Attention should be paid to the first footnote in the table, as not all elements of cost

are included. FACC multiplied the transponder costs shown in table 20 by a factor of 2 to arrive at a reasonable estimate of overall cost to the user. The results, annual transponder costs of \$52 000 to \$64 000, comparing favorably with Spacenet's 1982 charge of \$280 000 or to projected 1987 charges of \$190 000 per year.

Costs similar to FACC's overall space segment costs (table 19) were developed for space segments consisting of sets of current or filed-for satellites. These costs are compared with the costs of the FACC concepts in table 21. As for the transponder annual costs, a factor of 4 or 5 separates the FACC scenario space segment costs from those of a set of satellites providing equivalent capacity.

Ground terminal costs. - Estimates of ground terminal costs were presented earlier in the section "Costing." To compare platform versus conventional satellite ground segments, FACC assumed a scenario V platform replacing its equivalent capacity: approximately 13 conventional satellites. The platform serves three frequency bands. Therefore a given ground terminal would require three antennas for total connectivity. These three "terminals" would cost (based on figures in ref. 1) \$1.2 million (one C-band antenna at an average of \$600 000, one Ku-band antenna at an average of \$325 000, and one Ka-band antenna at an average of \$275 000).

To estimate the cost of the ground terminal for the associated equivalent nonplatform case, FACC looked at the current fractions of Intelsat ground terminals requiring full or partial connectivity. They estimated that approximately 40 percent of the locations require total connectivity (three antennas), 30 percent require two antennas, and the final 30 percent require only one antenna. FACC then calculated an equivalent normalized cost for total interconnectivity at a given location for the nonplatform space system: approximately \$2.9 million.

FACC acknowledges that the \$1.7 million difference per location node is high, as multiple terminals at a single location should not cost the multiple times their per-station costs. They claim that if a 30-percent savings per station were recognized, the savings per node would be on the order of \$875 000 for one scenario V concept versus its equivalent satellite complement.

Overall scenario rankings and implementability. - FACC ranked their concepts on the basis of bandwidth reuse, modulation efficiency, interference, reliability and availability, growth, complexity, and utilization. The results of this ranking and several pertinent comments concerning each scenario are as follows:

- (1) Scenario V (high-capacity CONUS)
 - (a) Optimized to CONUS FSS distribution
 - (b) All rigid reflectors
 - (c) Seven-satellite constellation satisfies demand through 2008
 - (d) Limited barriers
- (2) Scenario IV (high-capacity DBS)
 - (a) Single location for multiple users
 - (b) Ground assets minimized
 - (c) FSS payload tailored to DBS
 - (d) Onboard networking

- (3) Scenario II (medium-capacity CONUS)
 - (a) Replacement of mid-1990's payloads
 - (b) High-capacity digital Ka band
 - (c) Poor analog balance for CONUS (87 percent digital)
 - (d) No major barriers (orbital location restricted)
- (4) Scenario VI-A (international traffic)
 - (a) Highest throughput scenario
 - (b) Lowest utilization and capacity
 - (c) Major institutional barriers
 - (d) Suitable for integration with scenarios V and VI-B
- (5) Scenario VI-B (non-CONUS domestic)
 - (a) Efficient use of orbital arc
 - (b) Extremely difficult institutional barriers
 - (c) Suitable for integration with scenarios V and VI-A

FACC also commented briefly on the implementability of each of their scenarios. Scenario V was thought to be a very likely payload to be implemented if there is an adequate growth in demand to justify the large capacity and if the Ka-band hardware risks come down to commercially acceptable levels. The Ka-band payload is the greatest contributor to the per-channel cost reductions.

FACC believed second-ranked scenario IV to perhaps be the most likely concept to be developed, being the most technically sound. However, extensive plant-in-place resistance may considerably delay, or even prohibit, such development. Contributing to the implementability of scenarios V and IV was the fact they were both within U.S. regulatory bounds. Also, both could be operated by a single entity.

FACC thought scenarios II, VI-A, and VI-B to be of low probability. The scenario II concept is limited as to potential orbital locations by its DBS package. Additionally, the Ka-band digital capacity is much larger than the analog capacity.

FACC thought that scenarios VI-A and VI-B provide a technically sound and efficient use of the arc. However, they consider implementation to be nearly impossible because of the number of users involved, the international government coordination required, the necessary licenses, and nationalistic considerations.

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Concept weight and power. - The payloads developed by RCA that use advanced technologies are summarized in table 22 in terms of their weight and power requirements. The payload weights ranged from 1172 kg for concept 1 (LMSS) to 3155 kg for concept 4 (FSS/ISL/TDAS). The weights for Ford's scenarios ranged from 1617 to 3201 kg. The power requirements for the RCA concepts ranged from 8081 W for concept 1 to 18 946 W for concept 4. The power requirements for the Ford payloads ranged from 7426 to 35 035 W. RCA did not estimate the requirements for low-risk or emerging technologies.

Spectrum orbit utilization. - RCA summarized the spectrum/orbit utilization of the payload concepts in terms of the number of transponders per fre-

quency band and also the amount of frequency reuse per band (table 23). Because of their high reliance on spot beam coverage, RCA frequency reuse schemes are up to 9.1 times for C band, 6.3 times for Ku band, and 6.1 times for Ka band. The maximum throughputs (table 24) ranged from 22.4 Gb/s for concept 3 to 34.5 Gb/s for concept 4.

Cost comparisons. - RCA's cost comparisons differed from those of FACC. That is, RCA did not include total system costs (i.e., bus and nonrecurring costs) in the analysis because of the limited scope of the study in the costing task. Their system cost comparisons are based only on the recurring costs of the payload and certain elements of the ground segment. Differential costs were estimated for each platform concept to assess the economic merits relative to a nonplatform or standard satellite approach.

RCA determined that the major cost advantage for the platforms is that fewer ground terminals are required to provide connectivity than would be required with a nonplatform approach. The FSS concepts offer high capacity and frequency band cross-strapping that provide a high degree of connectivity from one orbital slot. An alternative nonplatform approach would require many satellites to provide similar capacity. The ground terminal population associated with the nonplatform approach would require additional antennas to provide the same degree of connectivity as the platform concept. RCA's cost comparisons dealt with the cost differential in terms of the ground terminal associated with a platform versus a nonplatform approach to providing the same services. Through the various assumptions detailed in the final report, RCA determined that a platform approach could save tens of millions to hundreds of millions of dollars because of the reduction of required ground terminal hardware due to the high degree of interconnectivity for the fixed service concepts.

Effect on plant in place. - RCA compared the effect on the existing ground segment for each concept relative to more typical satellites with less communications capacity. Concept 1 reduces the complexity of mobile unit antennas by eliminating the need for tracking or discriminating between multiple satellites. Concept 2 reduces the number of ground terminal antennas required for connectivity. Cross-strapping between frequencies eliminates the requirement for Ka band in most low-traffic-density areas. Concept 3 requires conversion to a standardized time-division multiple access transmission mode and increased use of Ka band in most high-traffic-density areas. Concept 4 eliminates the need for double-hop satellite link or terrestrial links from international gateways. The TDAS payload is consistent with the TDAS requirements generated by Stanford Telecommunications, Inc.

Overall concept rankings/concept implementability. - RCA developed and ranked four platform concepts (table 25). Concept 1 is a land mobile satellite service with CONUS and Canadian coverage in UHF and L band. RCA assumed that a single system owner/operator would capture 100 percent of the market with this system. This concept has a payload mass of 1172 kg and requires 8.1 kW of power.

Concept 2 provides FSS to CONUS through a combination of C, Ku, and Ka bands and has 50 percent of the total market share. RCA assumed that a single company would own and operate this system, which has four orbital slots dedicated to providing FSS services. The envisioned 1998 platform will carry 20 percent of the market demand and have a mass of 2144 kg and power require-

ments of 15.6 kW. Video distribution would be provided by two additional satellites.

Concept 3 also provides FSS to CONUS through C, Ku, and Ka bands. Again RCA assumed that a single company would own and operate this system, which would capture 50 percent of the future market for satellite services. This system would use six platforms, each with the capacity to carry 13 percent of the total FSS CPS traffic and 10 percent of the video distribution traffic. The payload mass and power of a 1998 platform in this concept are 1508 kg and 12.3 kW, respectively.

Concept 4 is a combination of the FSS of concept 2, intersatellite links that connect to Atlantic Ocean Region and Pacific Ocean Region satellites for CONUS-to-Europe/Africa and CONUS-to-Asia traffic, and a tracking data and acquisition satellite system (TDAS). The ISL's will provide the capacity to meet 100 percent of the projected future demand for those international services. The TDAS payload would serve as a component of the future TDAS system.

Although RCA did not rank or evaluate these four concepts in detail regarding implementability, they did discuss the pertinent technical and institutional issues. These issues are summarized here:

(1) LMSS concept

- (a) A single operator will have exclusive assignments of 10-MHz UHF and L band.
- (b) The design is sensitive to bandwidth allocation and forecast demand.
- (c) Frequency allocations currently do not exist.
- (d) The demand is uncertain (new service).
- (e) There is uncertainty in the politics of a joint U.S.-Canada venture.

(2) FSS concepts

- (a) The concept is based on commercial realism.
- (b) A single owner is envisioned, but it could be a partnership.
- (c) Growth in capacity is seen as a natural evolution.
- (d) The commercial planning horizon is short (<<1998).
- (e) There are market uncertainties:
 - (i) Softening demand
 - (ii) Competition from fiber optics
- (f) A platform is commercially acceptable if the risk can be reduced.
- (g) Space station services offer the potential for risk reduction.

RCA noted that the main driver behind platforms is industry economics. Platforms will have to provide an adequate return on investments.

CONTRACTOR CONCLUSIONS

Despite the dissimilarity in some of their concepts, FACC and RCA did arrive at a number of similar conclusions. These and others are summarized below, as are the contractors' recommendations for future NASA efforts.

Ford Aerospace and Communications Corporation

FACC considers the results of their study to be preliminary, with more definitive work being required to validate the conclusions drawn. One of their main conclusions is that economically and technologically, a constellation of large geostationary facilities is desirable in the mid to late 1990's. However, various factors may be barriers to implementation. FACC's specific conclusions included the following:

(1) Large platforms may provide significant economies of scale.

(2) Scenarios VI-A and VI-B could serve all Region 2 non-U.S. traffic with one facility of each type.

(3) A constellation of seven scenario V payloads, or combinations of scenarios V, VI-A, and VI-B, could serve all U.S. satellite traffic (with the exception of broadcast video and land mobile) in the year 2008.

(4) The most commercially viable payload would be similar to the scenario V payload. The payload can be replicated as many times as necessary to satisfy total CONUS demand.

(5) Major institutional, regulatory, and insurance issues exist, especially for scenarios VI-A and VI-B.

On the basis of their payload concepts, FACC concluded that the following major technological developments are needed:

- (1) Dual polarization reuse at Ka band
- (2) High-efficiency modulators and demodulators
- (3) High-speed, programmable frequency shifters
- (4) Large, rigid reflectors for high-frequency dual polarization
- (5) Lightweight onboard baseband processors and RF equipment
- (6) Spacecraft bus technologies to support the large GEO facilities

In addition to technology development, FACC indicated that additional study is necessary in some areas:

(1) The economics for using space station capabilities need to be evaluated as these capabilities mature.

(2) Payload development should be continued by selecting a concept and instituting detailed system implementation studies. Characteristics of assumed traffic distributions should be validated, and further optimization of the antenna and transponder configuration undertaken.

(3) The integration of a payload to a specific bus and transportation interface is required, and an operational system study should be conducted on the entirety.

Overall, FACC stated that given the potential economic benefits and the long time need to minimize the number of orbital locations used, it would be appropriate to continue the development of a large geostationary communications facility.

RCA Astro-Electronics Division

RCA, like Ford, concluded that platforms appear to be cost effective, are technologically feasible, and are desirable for the late 1990's if the demand for satellite communications services continues to grow. A more detailed and complete cost analysis that includes bus, launch, insurance, and operations costs is required to verify cost advantages. If communication platforms prove to be profitable for the communications industry, RCA predicts that an evolutionary process will take place for implementation. That is, spacecraft will continue to grow in capacity and could reach "platform size" about 1998 through a 10-year development process. These conclusions and others identified are listed below:

- (1) Platform requirements are driven by economic factors - the effect on "bottom line."
- (2) Platforms will probably be needed circa 1998 to meet growing demand.
- (3) Platforms appear to be cost effective.
- (4) Platforms offer improvements in connectivity.
- (5) Platforms will evolve over a 10-yr period.
- (6) Platform concepts are technically feasible.
- (7) There is a key role for NASA in long-range planning and technology development.
- (8) Platforms can significantly reduce the number of "standard satellites" needed to meet market requirements.
- (9) Major institutional, regulatory, and institutional issues exist for platform implementation.

Overall, the RCA study effort indicated the technical feasibility of the platform concepts and identified the technologies requiring further development before the platform concept can be implemented. The technology concerns were centered on antennas, onboard processors, large IF matrix switches, high-power SSPA's, ISL's, and Ka-band multiplexer filters.

RCA noted that the commercial satellite communications industry tends to focus on short-range planning (typically 5 yr). Thus RCA stated that NASA should play a key role in the long-term technology development process.

DISCUSSION OF FINDINGS

Both contractors arrived at a number of similar conclusions regarding large geostationary communications facilities. The contractors based their payload concept development in part on traffic forecasts published in 1983. These forecasts did not to any extent take into account fiber optics as a communications medium. Since the publication of the forecasts actual and planned fiber optics use has undergone a significant growth. Inroads of fiber optics on satellite-carried traffic may postpone the need for any large geostationary communications facilities.

Both contractors judged that large GEO facilities might provide economies of scale and other benefits over a group of smaller satellites for the same

magnitude of services. A more vigorous examination of this issue is necessary. The studies reported on herein were the first part of the first phase of a planned four-phase effort and considered only the payload portion of a GEO facility. However, the economics of a geostationary communications facility must be examined in the context of a payload, a bus, and a space transportation system considered as an operational whole. The results of such an operational system study could then be compared with other communications delivery systems to determine the more cost-effective or otherwise better system.

Both contractors cited various barriers for the payload concepts. These barriers, institutional (e.g., ownership and insurance) and regulatory, differed from payload concept to payload concept. It should be noted, however, that some or all of the barriers may be overcome if the need for the facilities is great, if significant economic motivation exists, or both.

At the outset of these studies the space station program was not a certainty. The contractors were to consider servicing, but in a cursory fashion. No in-orbit payload assembly was to be considered, but mating the spacecraft to orbital transfer vehicles, checking and calibrating the payload, and other orbital procedures were not ruled out. FACC considered GEO payload servicing unlikely for the timeframe of interest but from the limited review given the subject thought some LEO procedures may be worthwhile. RCA did not rule out GEO servicing as FACC did, considering such activities as spacecraft refueling for stationkeeping and robotic replacement of high-power, solid-state power amplifiers. RCA's GEO servicing considerations primarily involved prolonging the facility's operating life. Some would argue that prolonging operating life beyond the 10 yr achievable with current satellites is not particularly desirable because of likely technological obsolescence of the payload or change in service demand characteristics. In other words, they believe that technological upgrading of the payload is just as important as extending facility life. To provide guidance to communications vendors, studies should be performed to determine what type of GEO servicing makes sense to the vendors, the design effects of providing for such servicing, and the economics of such servicing relative to other alternatives (e.g., launching a new system).

The contractors have put forth various technological developments as desirable. Most are not platform peculiar, but rather apply to one particular payload or another. Development efforts may be warranted to improve the delivery of a particular service, to enable more efficient use of a particular frequency band, or for other reasons. Examples of such efforts are

- (1) Polarization tracking at Ka band
- (2) Intersatellite links
- (3) Satellite high-power amplifiers
- (4) A/D format conversion
- (5) Low-weight, low-power baseband processor

Development efforts are already under way with respect to some of these (e.g., intersatellite links). Others are being examined in a preliminary fashion to determine the degree to which further efforts are warranted.

Finally, large geostationary facilities are being examined as platforms for various Earth observation or other science payloads. It may be possible to combine science and communications payloads on a particular bus in the interest of cost effectiveness or other reasons. Studies should be performed

to examine the compatibility of science and communications payloads on a single geostationary facility, and what benefits, if any, might accrue from such a combination.

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TABLE 1. - SELECTED FACC PAYLOAD SCENARIOS

Scenario	Service	Coverage area	Frequency band	Weight, kg	Power, kW	Comments
II	Medium-capacity fixed satellite service (FSS) trunking and customer premises services (CPS); medium-power direct broadcast service (DDS)	Continental United States (CONUS)	Cu, Ku, and Ka	2064	12.7	Six Ka-based scanning beams
IV	FSS and high-power DBS television distribution	CONUS	Ku	1617	35.1	200-W/channel Ku-band DBS
V	High-capacity CONUS FSS trunking and CPS	CONUS	C, Ku, and Ka	2261	7.4	Seven satellites; can accommodate 100 percent of nonvideo year-2008 projected CONUS traffic
VI-A	High-capacity half-CONUS FSS trunking and CPS; Region 2 international; Western Atlantic maritime; and east-west inter-satellite links	Central and eastern CONUS; Atlantic Ocean Region Intelsat and maritime; domestic Latin America	C, Ku, Ka, and UHF/L	3200	10.4	Highest capacity scenario considered, but has major institutional and regulatory problems
VI-B	High-capacity half-CONUS FSS trunking and CPS; Region 2 international; Eastern Pacific maritime; and east-west inter-satellite links	Western CONUS; Pacific Ocean Region Intelsat and maritime; Central and South America	C, Ku, Ka, and UHF/L	2925	11.2	Can accommodate all projected year-2008 non-CONUS domestic traffic, but major institutional issues exist

TABLE 2. - SELECTED RCA PAYLOAD CONCEPTS

Concept	Services	Coverage area	Frequency band	Weight, kg	Power, kW	Comments
1	Land mobile satellite service	CONUS and Canada	UHF/L	1172	8.1	Addresses 100 percent of year-2008 demand for voice and digital service
2	High-capacity fixed satellite service (FSS) - trunking and customer premises services	CONUS	C, Ku, and Ka	2144	15.5	Addresses 20 percent of projected CONUS demand
3	Medium-capacity FSS and video distribution	CONUS	C, Ku, and Ka	1508	12.3	Addresses 13 percent of projected FSS demand and 10 percent of video distribution demand
4	High-capacity FSS; intersatellite links to European and Asian satellites; and tracking and data acquisition payload	CONUS and "Europe/Asia"	C, Ku, Ka, and W	3155	18.9	FSS payload of concept 2; addresses 100 percent of projected Atlantic Ocean and Pacific Ocean Region traffic; major institutional and regulatory issues exist

TABLE 3. - SUMMARY OF FACC COMMUNICATIONS SERVICES AGGREGATION SCENARIO SELECTION

Scenario	Rank	Service	Coverage area	Frequency band	Comment
I	4	High-capacity fixed satellite service (FSS) and customer premises service (CPS)	Continental United States (CONUS)	C, Ku, and Ka	Six Ka-band scanning beams
II ^a	2	Medium-capacity FSS and medium-power direct broadcasting system (DBS)	CONUS	C, Ku, and Ka	100-W Ku-band DBS; Ka-band FSS spots to 18 standard metropolitan statistical areas; six Ka-band scanning beams
III	3	Land mobile satellite service (LMSS)	CONUS	UHF/L	100 Beams
IV ^a	1	FSS and high-power DBS television distribution	CONUS	Ku	200-W/channel Ku-band DBS
V ^a	5	High-capacity FSS and LMSS	CONUS	C, Ku, and Ka	LMSS dropped in succeeding tasks
VI-A ^a	7	High-capacity, half-CONUS FSS; Region 2 international; east-west intersatellite links; and Western Atlantic maritime	Central and eastern CONUS; Atlantic Ocean Region Intelsat and maritime; domestic Latin America	C, Ku, Ka, and UHF/L	
VI-B ^a	6	High-capacity half-CONUS FSS; Region 2 international; east-west intersatellite links; and Eastern Pacific maritime	Western CONUS; Pacific Ocean Region Intelsat and maritime	C, Ku, Ka, and UHF/L	Service coverages changed in succeeding tasks
VII	8	High-capacity intra- and inter-Region 2 FSS; east-west intersatellite links; Region 2 DBS	Region 2	C, Ku, Ka, and UHF/L	Service coverages changed in succeeding tasks

^aSelected for further development.

TABLE 4. - SUMMARY OF RCA COMMUNICATIONS SERVICE AGGREGATION SCENARIO SELECTION

Rank	Service	Coverage area	Capacity, ^a percent	Frequency band	Comments
b ₁	Fixed satellite service (FSS) (trunking and customer premises service (CPS))	Continental United States (CONUS)	20	C, Ku, and Ka	Extensive use of spot beams
2	FSS (trunking and CPS)	CONUS	13	C, Ku, and Ka	Less demanding capacity requirements
b ₃	FSS (trunking, CPS, and video distribution)	CONUS	13 (trunk or CPS) 10 (video)	C, Ku, and Ka	C band for video distribution
b ₄	Land mobile satellite service (LMSS)	CONUS and Canada	^c 100	UHF/L	Voice radiotelephone service and digital data services
b ₅	FSS, intersatellite links, and data distribution	CONUS, east-west, and global	20	C, Ku, Ka, W (or optical), and S	Same FSS as concept; data distribution compatible with TDAS
6	FSS and LMSS	CONUS	20 (FSS) 100 (LMSS)	C, Ku, Ka, and UHF/L	Possible conflict of lifetime design between services
7	Direct broadcast service (DBS) and video distribution	CONUS	50	C and Ku	High-power DBS service
8	FSS and intersatellite links	Western hemisphere	20 (U.S.) 100 (non-U.S.)	C, Ku, Ka, and W (or optical)	Institutional and political issues
9	DBS	CONUS	50	Ku	Similar to high-power DBS satellite systems
10	DBS and video distribution	Western hemisphere	25 (U.S.) 50 (non-U.S.)	C and Ku	Institutional and political issues

^aPlatform capacity relative to total satellite addressable demand (1998).

^bSelected for further development and renumbered by RCA.

^cLMSS capacity sized to end-of-life demand.

TABLE 5. - FACC ANTENNA CONFIGURATIONS

Antenna system	Frequency, ^a GHz	Reflector
Scenario II		
C-band fixed satellite service (FSS)	6/4	Dual-grid reflector, 1.4 by 1.8 m diameter
Ku-band FSS	14/11	Dual-grid reflector, 2.44 m diameter
Ku-band direct broadcast service (DBS)	17/12	One solid 2.44-m-diameter reflector for transmitting and one solid 1.8-m-diameter for receiving
Ka-band FSS	30/20	One solid 4-m-diameter reflector for transmitting and one solid 2.7-m-diameter reflector for receiving
Scenario IV		
Ku-band DBS	17/12	One 2.44-m solid reflector; one 1.8-m solid reflector
Ku-band FSS	14/11	4-m dual-grid reflector
Scenario V		
C-band	6/4	4.6-m dual-grid reflector
Ku-band FSS	14/11	4.6-m dual-grid reflector
Ka-band FSS	30/20	One solid 4-m reflector for transmitting; one solid 2.7-m reflector for receiving (dual-shaped reflectors, each with subreflector)
Scenario VI-A		
C-band FSS	6/4	4.6-m dual-grid reflector
Ku-band FSS	14/11	4.6-m dual-grid reflector
Ka-band FSS	30/20	One solid 4-m reflector for transmitting; one solid 2.7-m reflector for receiving (dual shaped reflectors, each with (sub)reflector)
C-band international	6/4	One 5-m dual-grid and one 4-m dual grid reflector
C/L-band maritime	1.5-1.7 3.5-3.65 6.425-6.441	One solid 3-m reflector One solid 1.2-m reflector One solid 0.76-m reflector
GEO-GEO ^b	60	One gimbaled 3-m reflector for each inter-satellite link (ISL) (one east and one west)
Scenario VI-B		
C-band FSS (non-Continental United States)	6/4	9-m unfurlable reflector
Ku-band FSS (CONUS, Canada, and Mexico)	14/11	4.6-m dual-grid reflector
Ka-band FSS	30/20	One solid 4-m reflector for transmitting; one solid 2.7-m reflector for receiving (dual-shaped reflectors, each with subreflector)
Ku-band (Brazil)	14/11	1-m dual-grid reflector
C/L-band maritime	1.5-1.7 3.6-3.65 6.425-6.441	One solid 1.2-m reflector One solid 0.5-m reflector One solid 0.35-m reflector
GEO-GEO	60	One gimbaled 3-m reflector for each ISL (one east and one west)

^aTransmitting/receiving.^bGEO denotes geosynchronous Earth orbit.

TABLE 6. - SUMMARY OF PLATFORM CONSTELLATION

[Spare capacity for U.S. domestic service is included in the forecasts.
For seven scenario V/VI satellites to handle U.S. domestic FSS,
digital penetration must be approximately 70 percent.]

Scenario	Number of satellites	Traffic served
IV	3	U.S. domestic broadcast video
V	3	U.S. domestic fixed satellite service (FSS)
VI-A	2	U.S. domestic FSS, Atlantic Ocean Region international intersatellite links (ISL), and intraregional (except Canada)
VI-B	2	U.S. domestic FSS, non-U.S. domestic, Canada (international and regional), and Pacific Ocean Region international ISL

TABLE 7. - RCA CONCEPT 1 ANTENNA CONFIGURATION

Antenna system	Frequency, MHz	Reflector
Concept 1		
UHF voice	821-825/866-870	30-m offset reflective parabola; microstrip feed panels
L-band digital services	1553-1559/1654-1660	20-m offset reflective parabola; frequency-selective dichroic screen transmits L-band energy and illuminates 200 m of 30-m antenna (L-band reflective screen super- imposed on 30-m antenna; micro- strip feed panels)
Ku-band gateway	13 175-13 225/ 11 625-11 675	Single horn
Concept 2		
C-band spot beam C-band Continental United States (CONUS)	5.945-6.425/3.7-4.2	10.5-m unfurlable 2-m deployable
Ku-band spot beam	14.0-14.5/11.2-11.7	3.5-m deployable
Ku-band CONUS		1.5-m deployable
Ka band	27.5-30.0/17.7-20.2	3.0-m deployable; 4.5-m deployable
Concept 3		
C-band CONUS	5.945-6.425/3.7-4.2	2.0-m deployable
Ku band	14.0-14.5/11.2-11.7	2.0-m deployable
Ka band	27.5-30.0/17.7-20.2	3.0-m deployable; 4.5-m transmitting

^aTransmitting/receiving.

TABLE 8. - CRITICAL TECHNOLOGY USED BY FSS SCENARIOS

Technology	Scenario			
	II	V	VI-A	VI-B
Baseband processing: High-efficiency modulator/ demodulator	x	x	x	x
Analog-to-digital format conversion			x	
Antennas: Polarization tracking of Ka band for horizontal and vertical reuse	x	x	x	x
Dual polarizer for receiv- ing and transmitting bands			x	x
Transponders: High-speed programmable frequency source	x	x	x	x
Intersatellite links (RF or optical)			x	x

TABLE 9. - SUMMARY OF RCA CRITICAL TECHNOLOGY

Technology	Rank	Technical risk	Cost uncertainty	Concept	Critical areas
Antennas	1	High	High	All 4 (concept 1 highest)	30- and 10-m-diameter unfurlable reflectors; microstrip feed array
Onboard processor	2	High	High	2, 3, and 4	Demodulator mass power, size, and reliability
Intermediate-frequency switch	3	Moderately high	Moderate	2, 3, and 4	Crosstalk isolation; wide bandwidth; switching speed
Intersatellite links	4	Moderately high	Low	4	High-power GaAlAs transmitter; pointing and tracking; W-band reflector surface tolerance; wideband modulator/demodulator
Satellite high-power amplifier	5	Moderate	Low	2, 3, and 4 (Ka and W band)	Dual-mode power; redundancy
Multiplexer filters	6	Low	Low	2, 3, and 4 (Ka and W band)	Ka band or higher input and output

TABLE 10. - FACC PROJECTED COSTS OF PAYLOAD ELEMENTS
INCORPORATED IN SCENARIOS

Payload element	Scenario				
	II	IV	V	VI-A	VI-B
	Cost, million of dollars				
C-band fixed satellite service	4.5	----	----	----	----
C-band FSS	----	----	7.9	7.8	----
C/L-band maritime (Atlantic)	----	----	----	3.4	----
C/L-band maritime (Pacific)	----	----	----	----	2.4
Region 2 non-CONUS	----	----	----	27.8	27.1
Ku-band Region 2 non-CONUS	----	----	----	----	15.7
Ku-band FSS	15.2	28.7	32.0	32.0	32.0
Ku-band direct broadcast service (DBS)	11.3	38.5	----	----	----
Ka-band FSS	20.0	----	20.0	20.0	20.0
Ka-band scanning beam	30.1	----	30.1	30.1	30.1
60-GHz intersatellite links	----	----	----	5.1	4.3
Total	81.1	67.2	90.0	126.2	131.6

TABLE 11. - FACC ESTIMATED COST OF GROUND TERMINALS

Frequency band	Antenna diameter, m	Type	Recurring cost, thousands of dollars
C	10-15	Transmitting and receiving	200-1000
	2-8	Transmitting and receiving	10-50
	2-5	Receiving only	2-10
Ku	7-10	Time-division multiple access transmitting and receiving	150-500
	2-3	Frequency-division multiple access transmitting and receiving	4-5
	1	Direct broadcast service - receiving only	0.4-0.6
Ka	5-7	Time-division multiple access transmitting and receiving	250-300
	2-3	Time-division multiple access transmitting and receiving	100-170

TABLE 12. - RCA COMMUNICATIONS PLATFORM PAYLOAD RECURRING COST

Concept	Mass, kg	Cost, millions of dollars	Cost per mass, thousands of dollars/kg	Transponder channels ^a	Weight per channel, kg	Cost per channel, thousands of dollars	Cost driver	Percent of total cost of concept
Land mobile satellite service (LMSS)								
Antenna	200	24	120	138	8.5	870	Antenna	24
Transponder	972	96	99				Receiver	23
Total	1172	120	102				Solid-state power amplifier (SSPA) Electronic power converter	17
Fixed satellite service (FSS) (20 percent)								
Antenna	332	14	38				Input/output multiplexer	45
Transponder	1812	216	119	511	4.2	450	Baseband proc- essor (BBP) SSPA	24
Total	2144	230	107					14
FSS (13 percent)								
Antenna	208	8	36				Input/output multiplexer	48
Transponder	1300	158	121	373	4.0	445	BBP SSPA	27
Total	1508	166	109					16
Tracking and data acquisition, intersatellite links, and FSS								
Antenna	567	25	42				Input/output multiplexer	39
Transponder	2588	296	115	580	5.4	553	BBP SSPA	23
Total	3155	321	102					16
Satellites built in 1984								
C-band antenna	42	1.4	33					
C-band transponder	88	10.4	118	24	5.4	492		
C-band total	130	11.8	91					
Ku-band antenna	32	1.2	38					
Ku-band transponder	131	15.4	118	24	6.8	692	Traveling wave tube amplifier	41
Ku-band total	163	16.6	102					

^aTransponder channel bandwidth, from 60 kHz to 1 MHz for LMSS; 35 MHz for FSS.

TABLE 13. - SUMMARY OF RCA FIXED SATELLITE SERVICE GROUND TERMINAL COSTS

Service	Frequency band	Antenna diameter, m	Recurring antenna cost, thousands of dollars	Recurring low-noise amplifier cost, thousands of dollars	Total cost, thousands of dollars
Trunking	C	10	150	40	190
	Ka	10	350	40	390
Customer premises	Ku	2	1	15	16
	Ka	2	2	18	20

TABLE 14. - CHARACTERISTICS OF FACC SCENARIO PAYLOADS

Payload element	Scenario									
	II		IV		V		VI-A		VI-B	
	Weight, kg	Power, W	Weight, kg	Power, W	Weight, kg	Power, W	Weight, kg	Power, W	Weight, kg	Power, W
Projected technology										
C-band fixed satellite service (FSS) (domestic)	89	659	---	---	246	708	246	708	---	---
C-band FSS (international)	---	---	---	---	---	---	750	2 166	---	---
C-band FSS (non-Continental United States (non-CONUS))	---	---	---	---	---	---	---	---	574	1 903
Ku-band FSS (CONUS)	261	2 522	605	5 075	523	785	523	785	523	785
Ku-band FSS (non-CONUS)	---	---	---	---	---	---	---	---	186	1 796
Ku-band DBS	223	3 876	1012	29 960	---	---	---	---	---	---
Ka-band FSS (CONUS)	1492	5 933	---	---	1492	5933	1492	5 933	1492	5 933
Maritime	---	---	---	---	---	---	79	649	44	649
Intersatellite links	---	---	---	---	---	---	111	160	107	131
Total	2065	12 990	1617	35 035	2261	7426	3201	10 401	2926	11 197
Emerging technology										
C-band FSS (domestic)	121	922	---	---	327	1001	327	1 001	---	---
C-band FSS (international)	---	---	---	---	---	---	987	3 140	---	---
C-band FSS (non-CONUS)	---	---	---	---	---	---	---	---	745	2 704
Ku-band FSS (CONUS)	315	3 444	751	7 052	812	1164	812	1 164	812	1 164
Ku-band FSS (non-CONUS)	---	---	---	---	---	---	---	---	301	2 751
Ku-band DBS	278	4 554	1227	34 060	---	---	---	---	---	---
Ka-band FSS (CONUS)	2007	6 849	---	---	2007	6849	2007	6 849	2007	6 849
Maritime	---	---	---	---	---	---	105	855	140	224
Intersatellite links	---	---	---	---	---	---	147	285	107	131
Total	2721	15 769	1978	41 112	3146	9014	4382	13 294	4068	14 547

TABLE 15. - FACC EFFECTIVE FREQUENCY REUSE FACTORS

Application	Scenario				
	II	IV	V	VI-A	VI-B
	Number of times reused				
C-band Continental United States (CONUS)	2	--	4	4	----
C-band Region 2 non-CONUS	----	--	----	9	9
Ku-band CONUS fixed satellite service	3	3	9	9	9
Ku-band CONUS direct broadcast service	----	4	----	----	----
Ku-band Region 2 non-CONUS	----	--	----	----	3.2
Ka-band CONUS trunking (fixed beam)	7.6	--	12.2	12.2	12.2
Ka-band CONUS customer premises service (scanning beams)	5.8	--	12.2	12.2	12.2
Maritime	----	--	----	1	1

TABLE 16. - SUMMARY OF FACC MODULATION CAPACITY ASSUMPTIONS

Modulation technique	Capacity (at 36 MHz)
Eight-phase phase shift keying	72 Mb/s
Companded single sideband	6000 half voice circuits
Frequency division multiplexed or frequency multiplexed	2800 half voice circuits
Single channel per carrier	1800 half voice circuits
Video (frequency modulated)	2.5 channels
Staggered quadrature phase shift keying	^a 1.5 Gb/s

^aPer intersatellite link channel.

TABLE 17. - FACC MAXIMUM THROUGHPUT BY SCENARIO

Application	Scenario			
	II	V	VI-A	VI-B
	Throughput, Gb/s			
Ka-band trunking	49.9	49.9	49.9	49.9
Ka-band customer premises services	8.6	8.6	8.6	8.6
Ku-band fixed satellites services	5.2	15.6	15.6	17.5
C-band	3.5	6.9	14.2	5.7
Intersatellite links	----	----	4.5	3.0
Total	67.0	81.0	93.0	85.0

TABLE 18. - FACC SPACE SEGMENT COST ASSUMPTIONS

[No development costs included. Perigee and apogee stage costs included in launch costs. Rockwell study used for estimating launch costs (in millions of dollars), 44.6 1n (BOL weight, 1b) - 293.2 1b.]

Component	Spacecraft weight allocation at beginning of life (BOL), percent	Bus costs
Payload	31	For large spacecraft: \$40 million recurring plus \$20 million for integration and launch operations For very large spacecraft: \$60 million recurring plus \$30 million for integration, launch, and low-Earth-orbit operations
Bus	47	
Stationkeeping fuel (10 yr)	22	

TABLE 19. - FACC SPACE SEGMENT COSTS

Scenario	Recurring payload	Bus	Launch	Total
Cost, millions of 1984 dollars				
II	81	60	134	275
IV	67	60	123	250
V	90	60	138	288
VI-A	126	90	154	370
VI-B	132	90	150	372

TABLE 20. - FACC TRANSPONDER COSTS PER YEAR^a

Communications	Scenario			
	II	V	VI-A	VI-B
Voice and data				
Cost per satellite, millions of dollars	^b 237	288	370	372
Effective bandwidth, GHz	32.5	35.9	44.3	42.4
Cost for 36 MHz per yr, ^c thousands of dollars	26	29	30	32
Video				
Cost per satellite, millions of dollars	^a 38	250	----	----
Number of channels	16	112	----	----
Cost for 24 MHz per yr, ^c thousands of dollars	238	223	----	----

^aCosts per year do not include profit for the manufacturer, operating costs, recovery of nonrecurring costs, or profits for the operator.

^bBus and launch costs are prorated, based on payload costs for direct broadcast system and communications.

^c10-yr life.

TABLE 21. - FACC ALTERNATIVE APPROACHES TO PROVIDING EQUIVALENT CAPACITY

Frequency band	Number transponders	Frequency, MHz	"Equivalent" satellite	Number required	Costs, millions of dollars	
					Satellite	Launch
Scenario II (\$237 million)						
C	24	36	Satcom	1	40	35
Ku	24	54	GTE	1.6	50	35
Ka	52	500	Hughes	5.9	90	75
	18	240	32x150 MHz	---	--	--
Total cost	\$1185					
Scenario V (\$287 million)						
C	48	36	Satcom	2	40	35
Ku	108	36	GTE	4.8	50	35
Ka	52	500	Hughes	5.9	90	75
	18	240	-----	---	--	--
Total cost	\$1531					
Scenario VI-A (\$370 million)						
C	48	36	Satcom	2	40	35
Ku	108	36	GTE	4.8	50	75
Ka	52	500	Hughes	5.9	90	75
	18	240	-----	---	--	--
C-international	---	---	I-VI	2	65	75
C/L	---	---	Inmarsat	1	35	35
Total cost	\$1881					
Scenario VI-B (\$372 million)						
Ku	108	36	GTE	4.8	50	35
Ka	52	500	Hughes	5.9	90	75
	18	240	-----	---	--	--
Domestic	---	---	-----	---	--	--
Canada	---	---	Anik	2	40	35
Mexico	---	---	Morales	1	30	35
C-international	---	---	Brazilsat	2	40	35
Other Latin	---	---	Pan Am Sat	1	40	35
American/	---	---	-----	---	--	--
Caribbean	---	---	-----	---	--	--
C/L	---	---	Inmarsat	1	35	35
Total cost	\$1901					

TABLE 22. - CHARACTERISTICS OF RCA SCENARIO PAYLOADS - PROJECTED TECHNOLOGY

Payload element	Concept							
	Weight, kg	Power, W	Weight, kg	Power, W	Weight, kg	Power, W	Weight, kg	Power, W
C-band fixed satellite service (FSS) (domestic)	----	----	290.9	664	77.6	688	290.9	664
Ku-band FSS (domestic)	----	----	243.8	3 560	125.2	2 082	243.8	3 560
Ka-band FSS (domestic)	----	----	1364	11 084	1163	9 360	1519	12 462
Intermediate-frequency time-division multiple access/circuit switching	----	----	51	200	42	160	58.5	230
Other hardware: filters, coaxial cables, waveguides,	----	----	194.3	-----	100	-----	207	-----
UHF and L-band land mobile satellite service	1172	8081	-----	-----	-----	-----	-----	-----
W-band intersatellite links	----	----	-----	-----	-----	-----	196	580
Tracking and data acquisition system	----	----	-----	-----	-----	-----	639.4	1 450
Total	1172	8081	2144	15 508	1508	12 290	3155	18 946

^aBased on 1993 space-qualified technology.

TABLE 23. - RCA ORBIT UTILIZATION

Frequency band	Concept			
	1	2	3	4
Number of transponders				
UHF (1 MHz)	61	---	---	---
L (160 kHz)	77	---	---	---
C (36 MHz)	---	109	24	109
Ku (36 MHz)	---	76	41	76
Ka (36 MHz)	---	326	308	366
Total	138	511	373	551
Frequency reuse, number of times				
UHF	7.9	---	---	---
L	1.1	---	---	---
C	---	9.1	2.0	9.1
Ku	---	6.3	3.4	6.3
Ka	---	5.4	5.1	6.1

TABLE 24. - RCA MAXIMUM THROUGHPUT BY CONCEPT

Application	Concept			
	1	2	3	4
	Number of channels	Throughput, Gb/s		
C band	----	6.5	1.4	6.5
Ku band	----	4.6	2.5	4.6
Ka band	----	19.6	18.5	22.0
Intersatellite links	----	-----	-----	2.4
Tracking and data acquisition system	----	-----	-----	1.0
UHF	4508	-----	-----	-----
L band	662	-----	-----	-----
Total	----	30.7	22.4	35.6

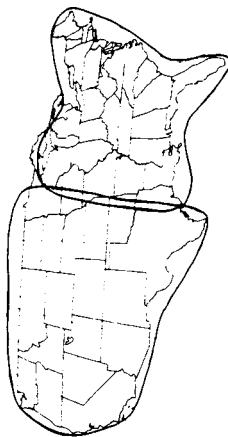
TABLE 25. - SUMMARY OF RCA COMMUNICATIONS PAYLOAD CONCEPTS

[Ownership, single company.]

Concept	Area	Frequency band	Market share in 1998, percent	Number of slots	Platform capacity, percent of 1998 traffic	Payload weight, kg	Power, kW
1	Continental United States (CONUS) and Canada	UHF/L	100	1	100	1172	8.1
2	CONUS	C, Ku, and Ka	50	4	20	2144	15.5
3	CONUS	C, Ku, and Ka	50	6	^a 13	1508	12.3
4	CONUS Europe and Asia Global	C, Ku, and Ka	50	1	20	3155	18.9
			100	--	100	----	----
		W, S, and L	100	--	100	----	----

^a10 Percent television.

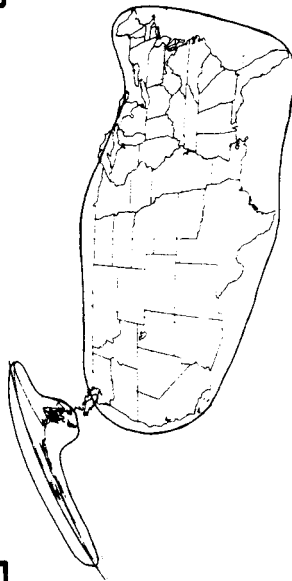
DIRECT BROADCAST - 16 CHANNEL



**Ku: 100 W PER CHANNEL OF 24 MHz
MEDIUM POWER**

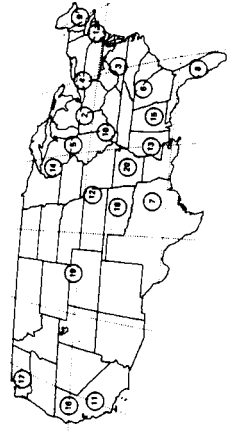
POWER: 3,900 watts
MASS: 223 kg

COMMUNICATIONS - 65 Gb/s

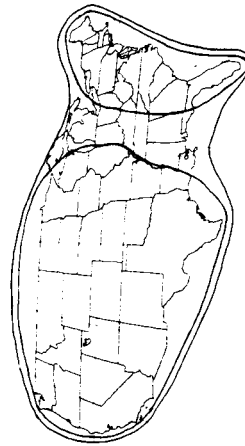


**C-BAND: 24 CHANNEL OF 36 MHz
(1.7 Gb/s)**

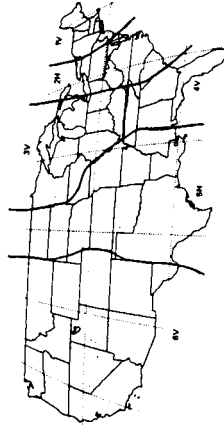
**COMMUNICATIONS PLATFORM
OF ~ 2064 kg
12714 watts**



**Ka FIXED: 20 BEAM
38 CHANNEL OF 500 MHz
(38 Gb/s)**



**Ku: 24 CHANNEL OF 54 MHz
(2.6 Gb/s)**



**Ka SCAN: 6 AREAS
18 CHANNELS OF 240 MHz
14 CHANNELS OF 500 MHz
(23 Gb/s)**

POWER: 8814 watts
MASS: 1,841 kg



**Ford Aerospace &
Communications Corporation**

FIGURE 1. - SERVICES ALLOCATION FOR FACC SCENARIO II.

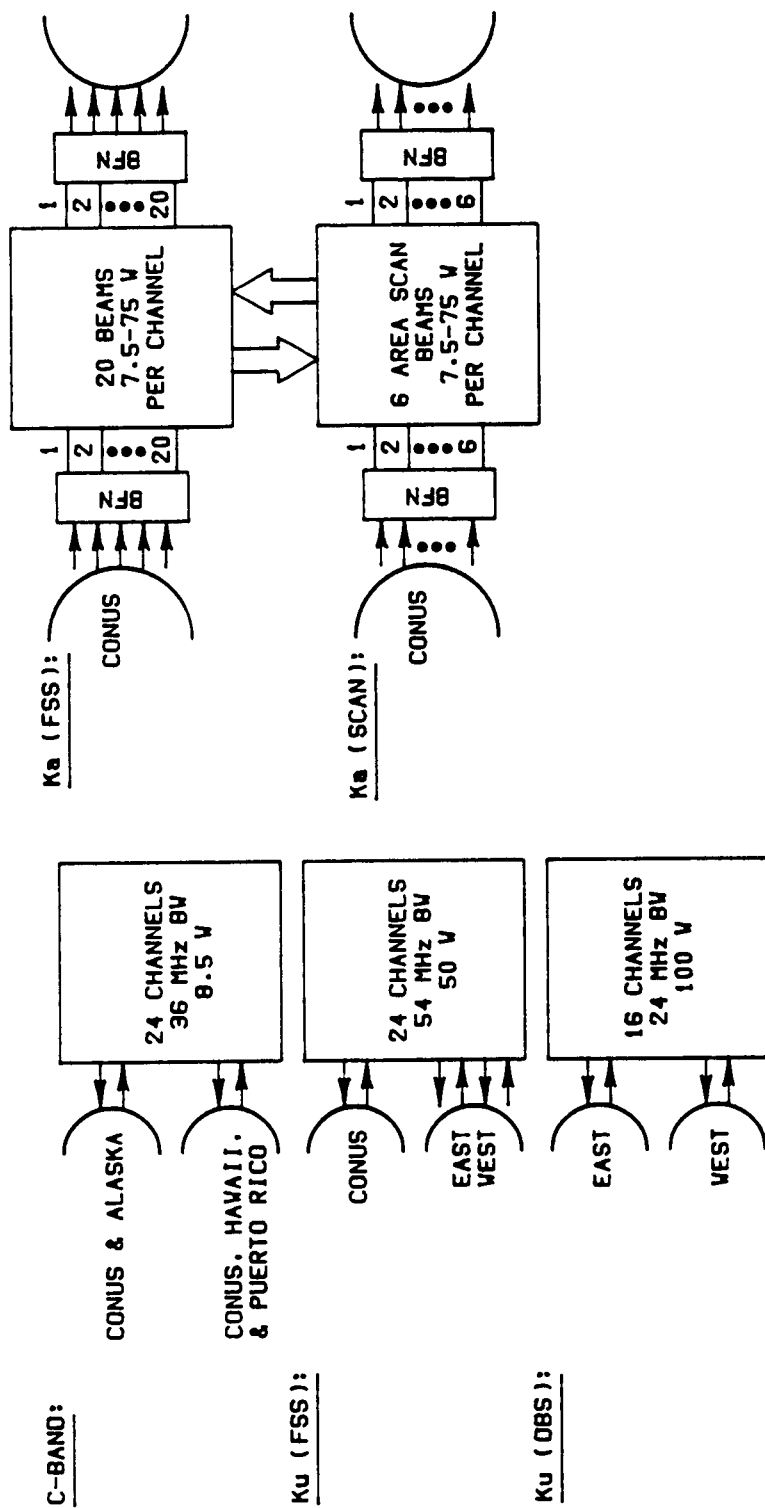
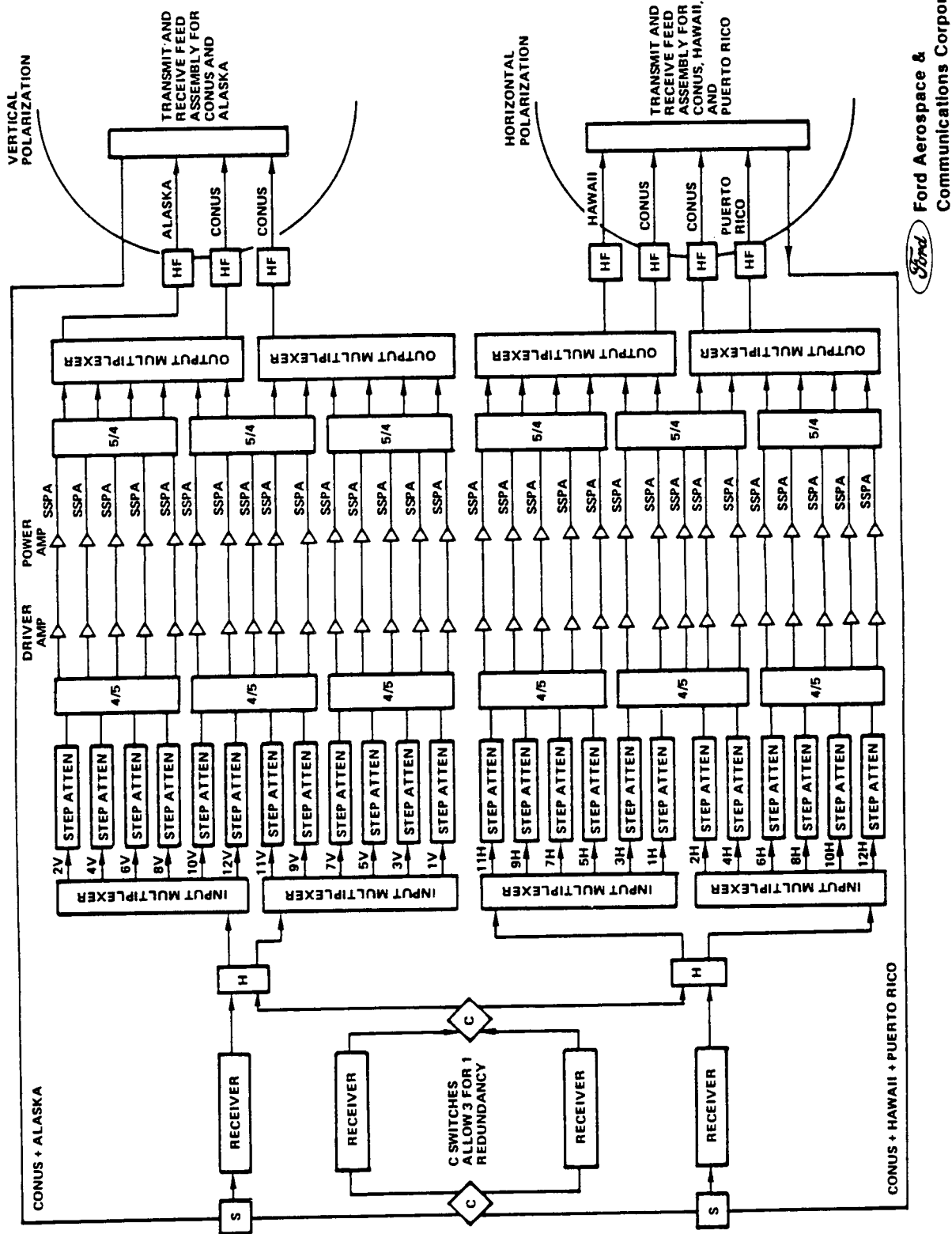
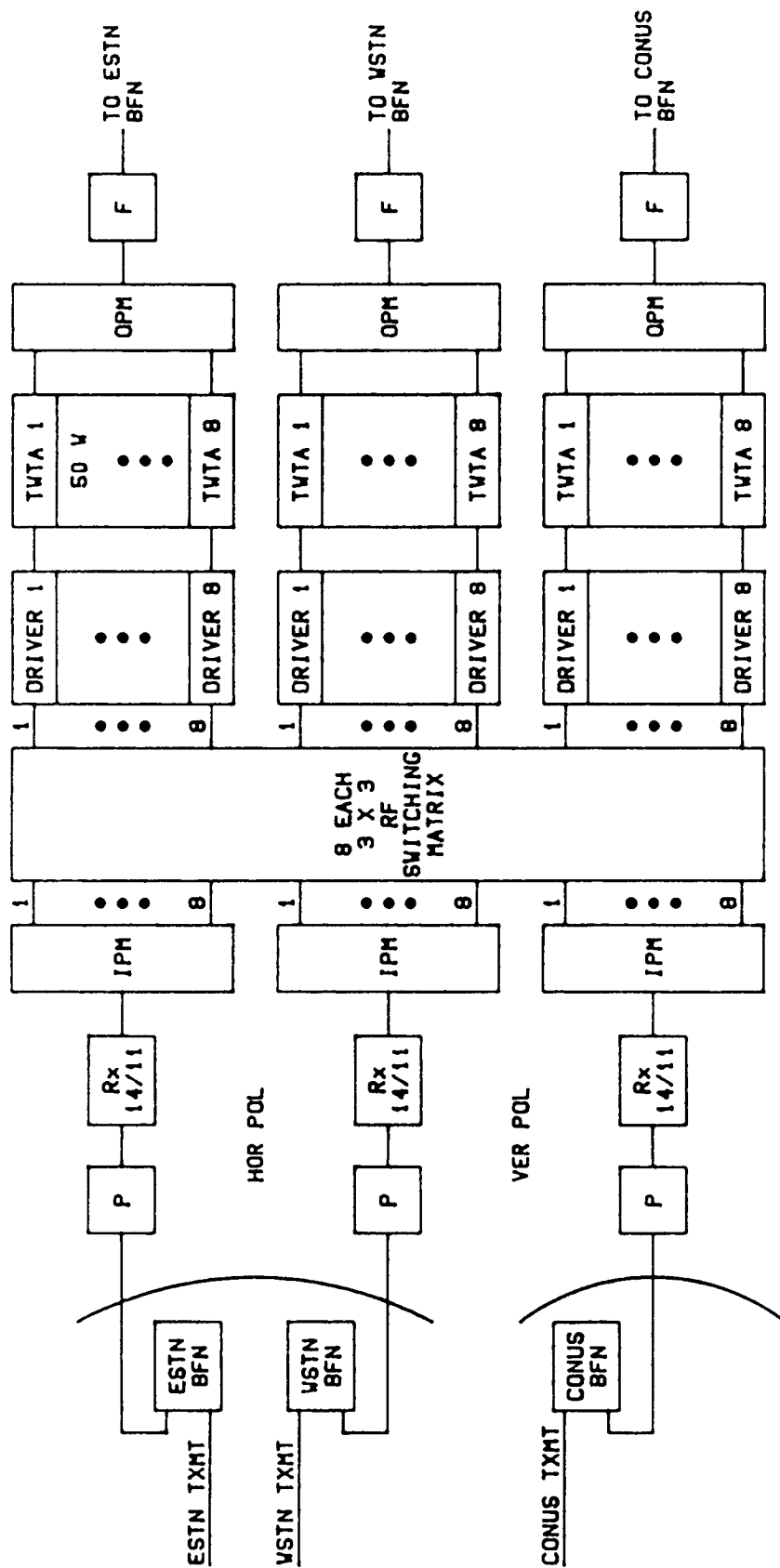


FIGURE 2. - OVERVIEW OF FACC SCENARIO II PAYLOAD.



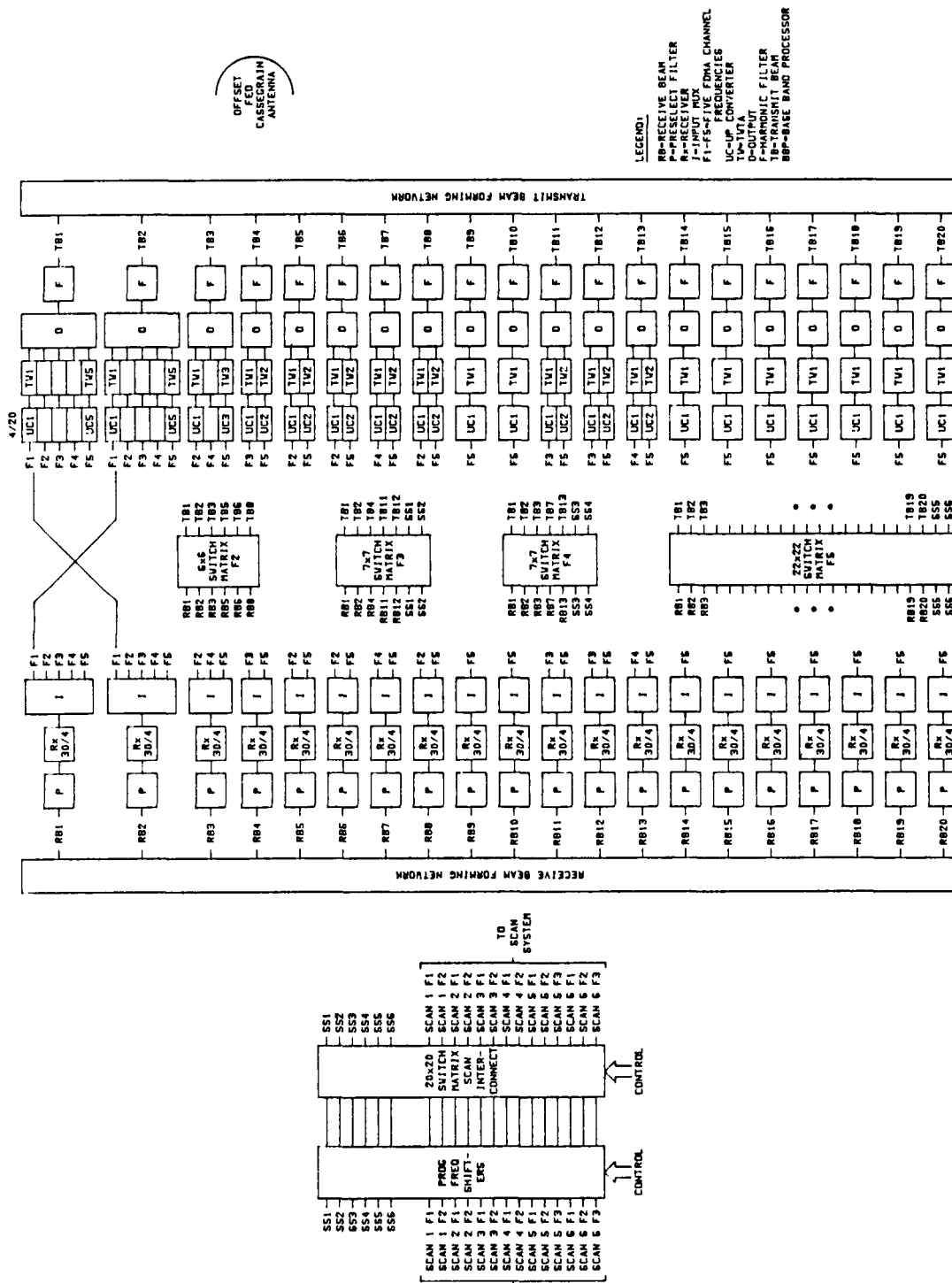
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FIGURE 3. - BLOCK DIAGRAM OF FACC SCENARIO II C-BAND FIXED SATELLITE SERVICE PAYLOAD.



P: PRESELECT FILTER
 BFN: BEAM FORMING NETWORK
 IPM: INPUT MULTIPLEXER
 OPM: OUTPUT MULTIPLEXER
 F: HARMONIC FILTER
 TXMT: TRANSMITTER

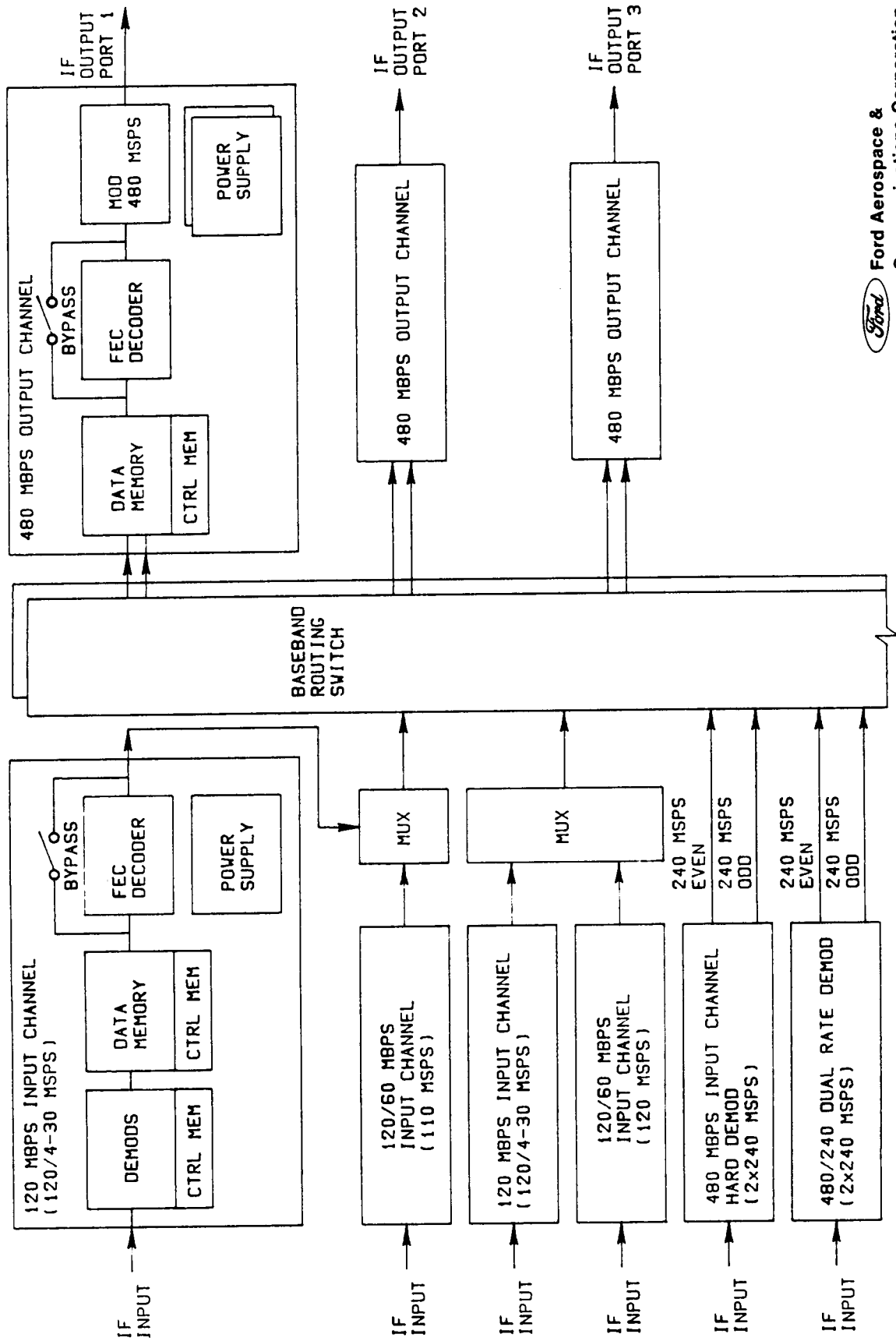
FIGURE 4. - BLOCK DIAGRAM OF FACC SCENARIO 10 II KU-BAND FIXED SATELLITE SERVICE PAYLOAD.



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FIGURE 5. - BLOCK DIAGRAM OF FACC SCENARIO 11 KA-BAND FIXED SATELLITE SERVICE PAYLOAD.

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FIGURE 7. - TYPICAL BASEBAND PROCESSOR INPUT/OUTPUT CHANNEL PER SCANNING BEAM.



FIGURE 8. - BLOCK DIAGRAM OF FACC SCENARIO II KU-BAND DIRECT BROADCAST SERVICE PAYLOAD.

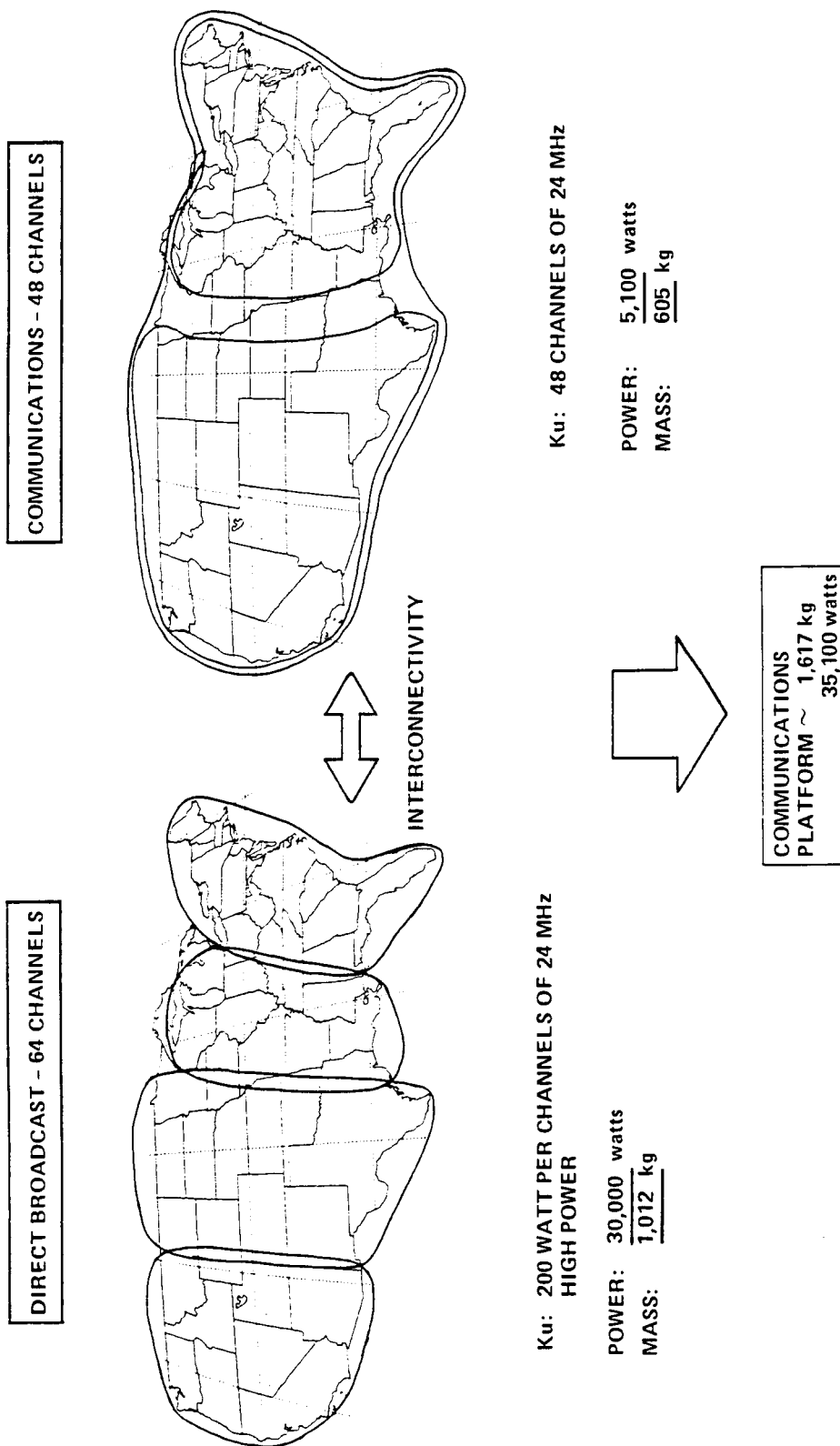


FIGURE 9. - SERVICES ALLOCATION FOR FACC SCENARIO IV.

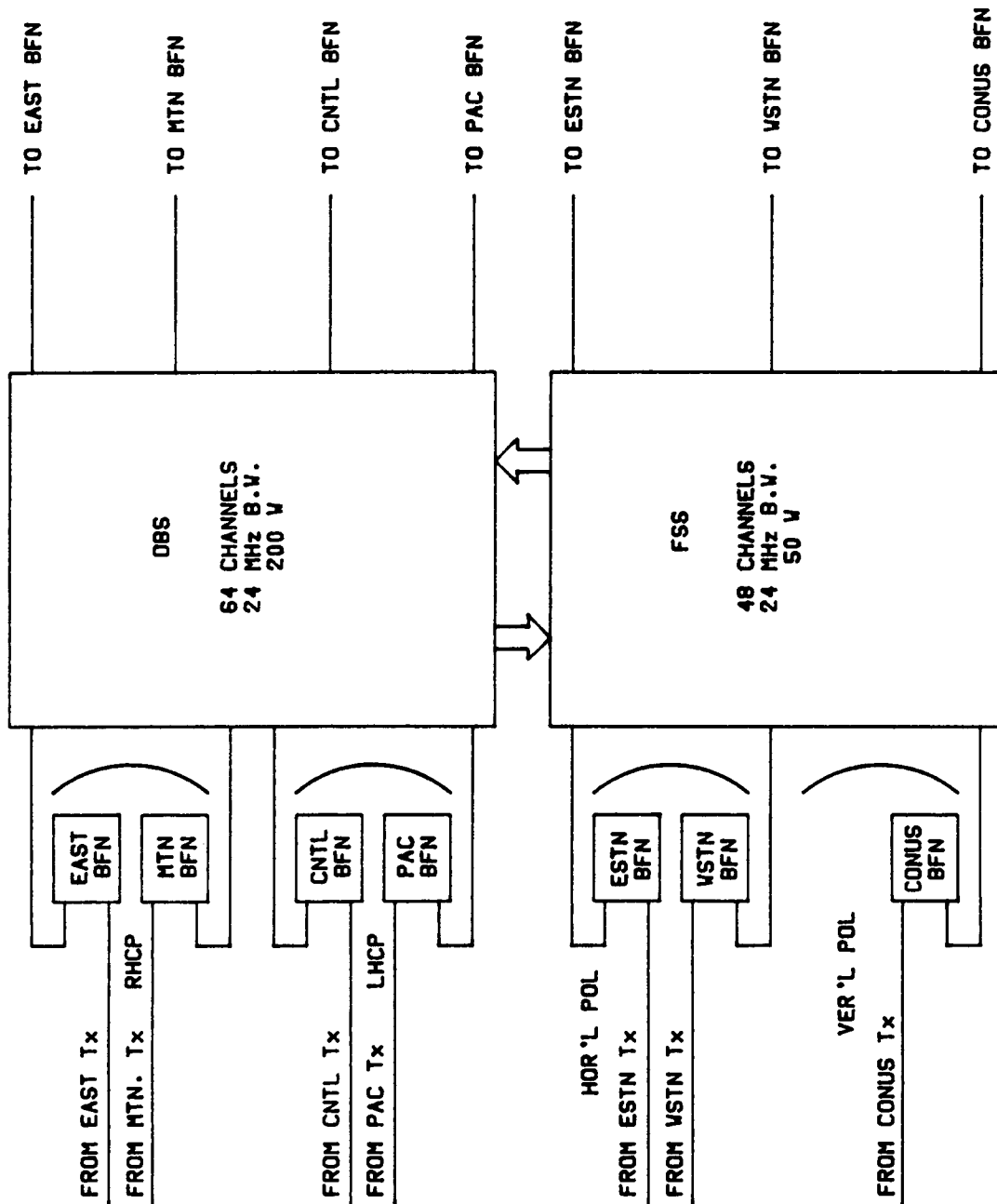
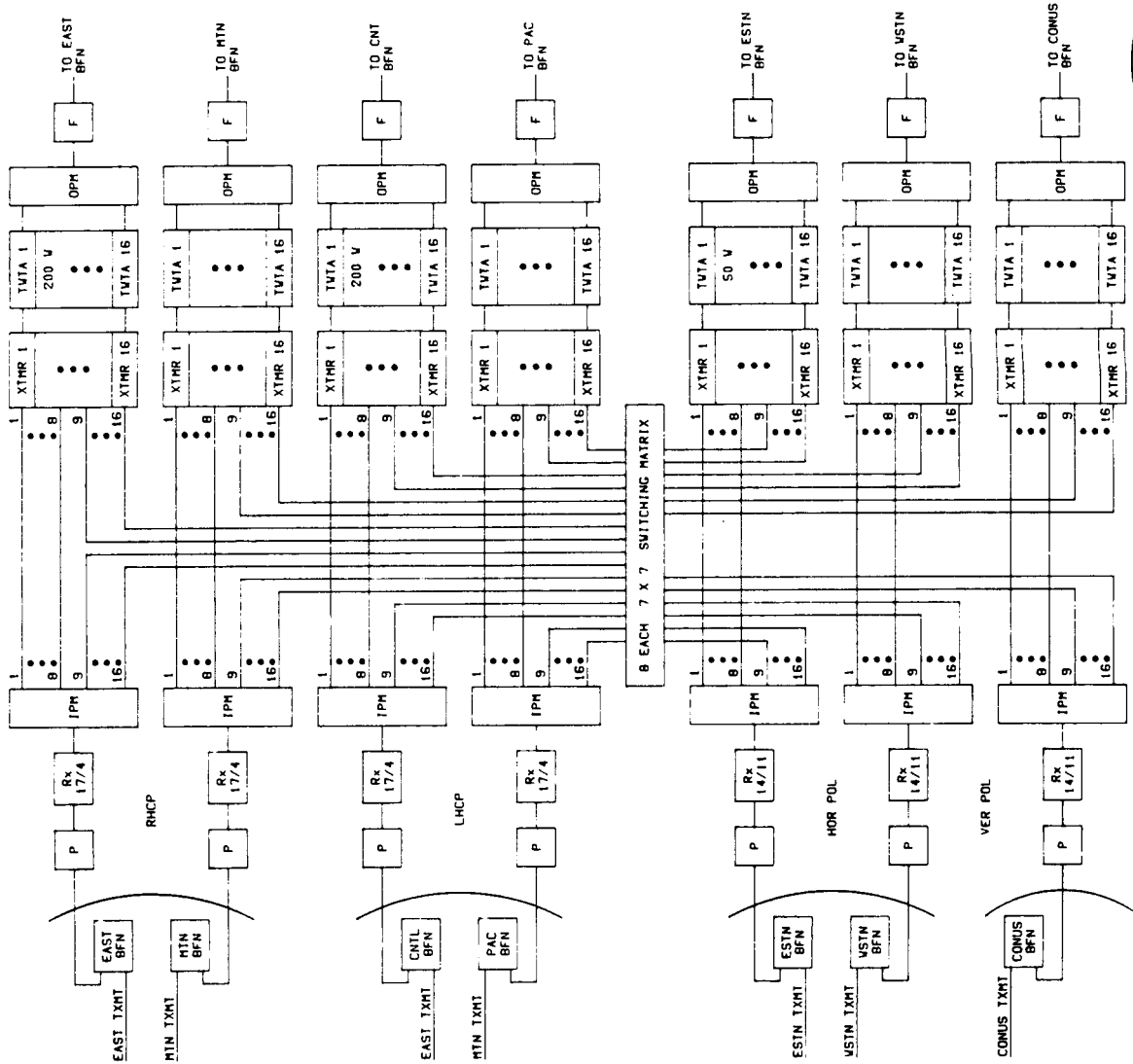


FIGURE 10. - OVERVIEW OF FACC SCENARIO IV PAYLOAD.



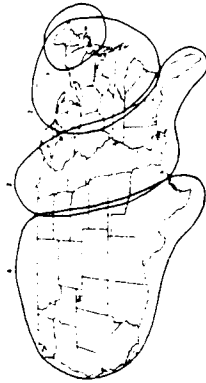
P: PRESELECT FILTER
 BFN: BEAM FORMING NETWORK
 IPM: INPUT MULTIPLEXER
 OPM: OUTPUT MULTIPLEXER
 F: HARMONIC FILTER
 Rx: RECEIVER

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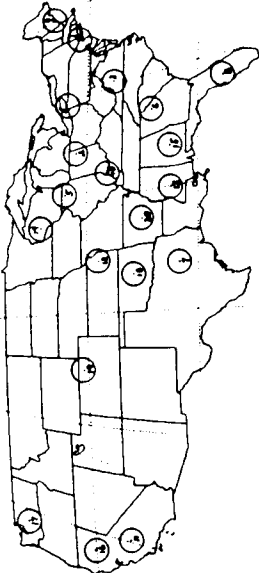
FIGURE 11. - BLOCK DIAGRAM OF FACC SCENARIO IV PAYLOAD.

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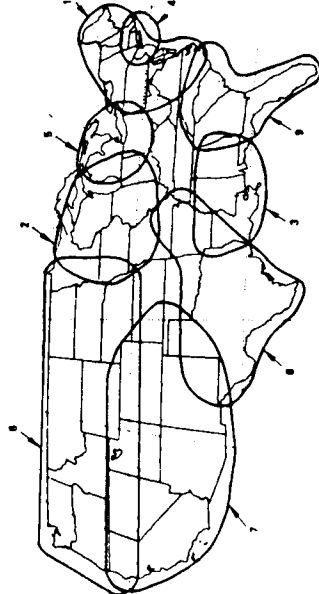
COMMUNICATIONS - 72 Gb/s



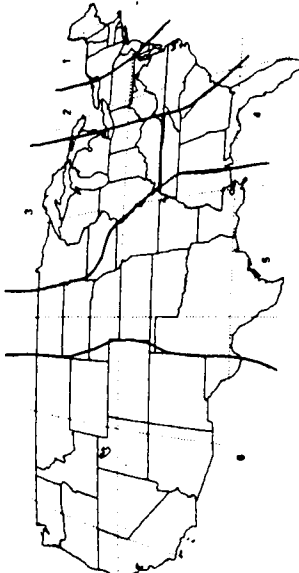
C-BAND: 48 CHANNELS OF 36 MHz
(3.5 Gb/s)



KA FIXED: 20 BEAM
38 CHANNELS OF 500 MHz
(38 Gb/s)



KU-BAND: 108 CHANNELS OF 36 MHz
(7.8 Gb/s)



KA SCAN 6 AREAS
18 CHANNELS OF 240 MHz
14 CHANNELS OF 500 MHz
(23 Gb/s)



COMMUNICATIONS PAYLOAD
OF ~ 2,261 kg
7,426 watts

FIGURE 12. - SERVICES ALLOCATION FOR FACC SCENARIO V.

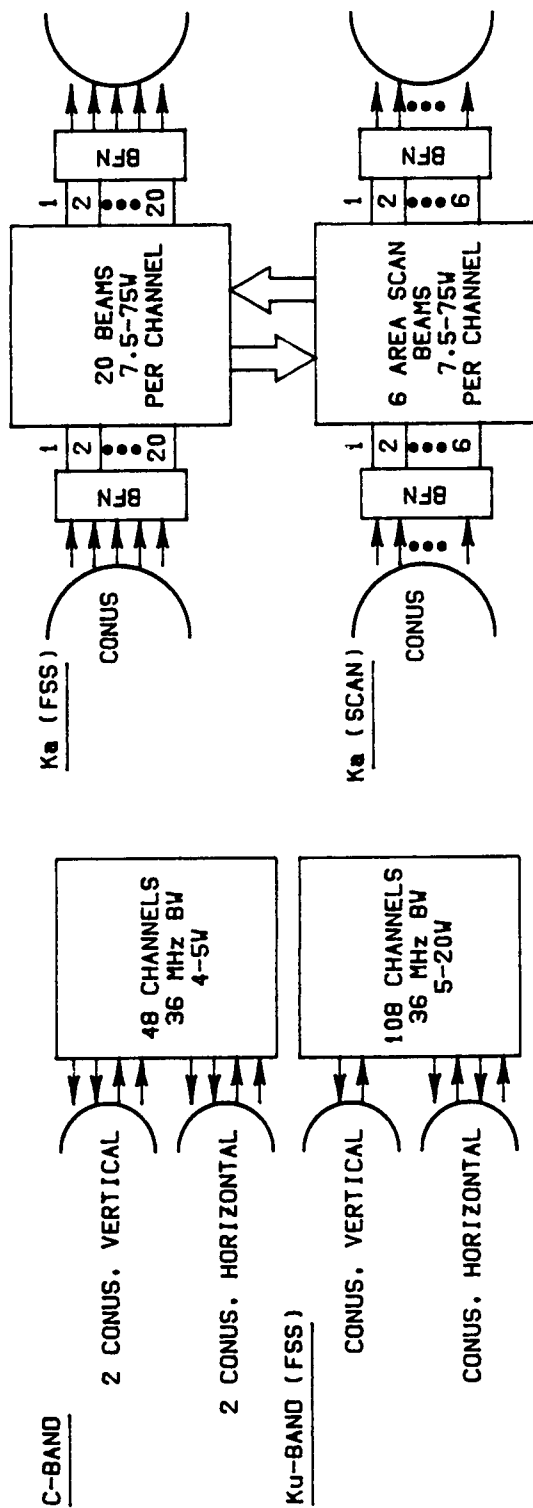


FIGURE 13. - COMPOSITE BLOCK DIAGRAM OF FACC SCENARIO V PAYLOAD.

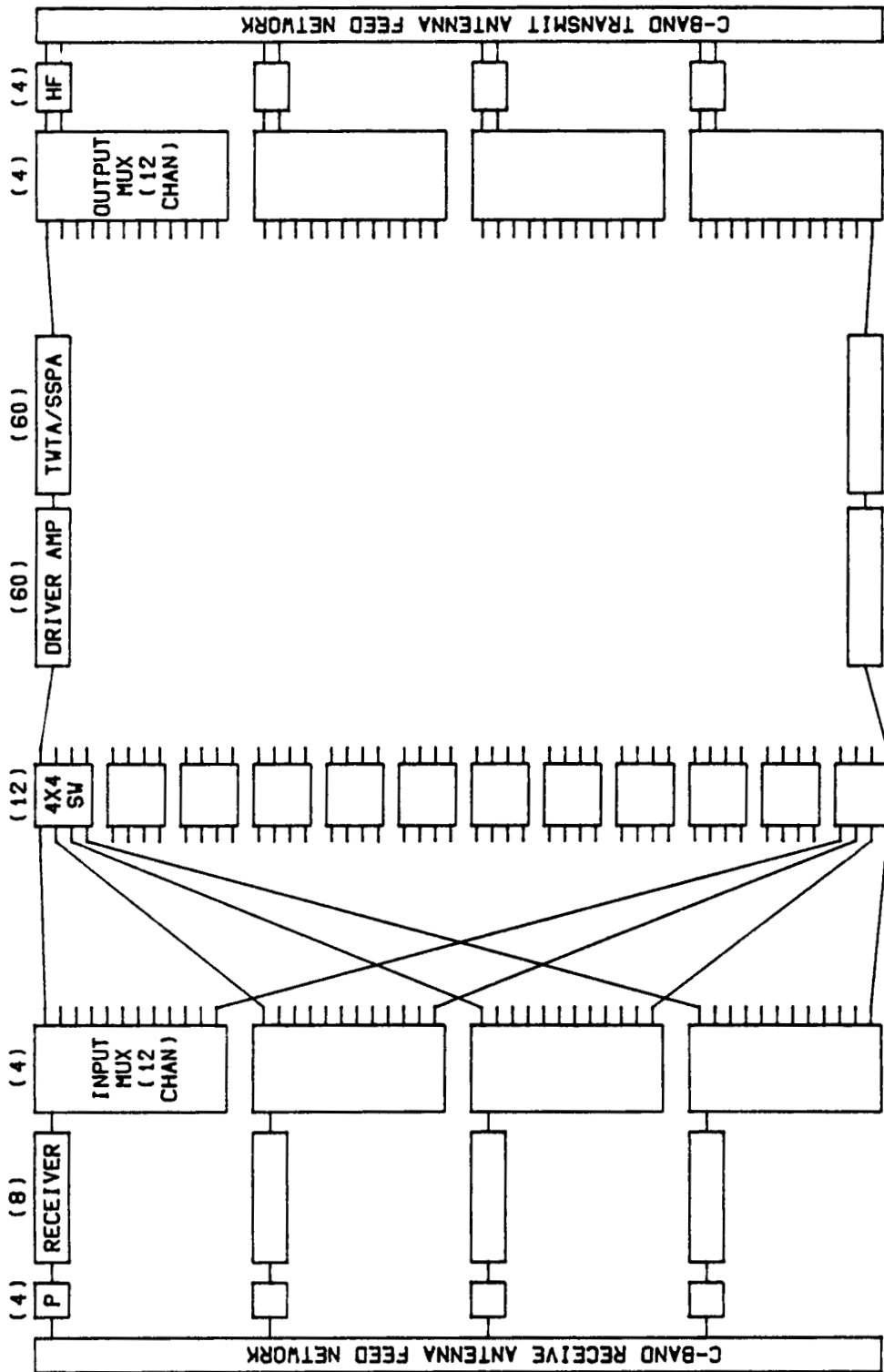
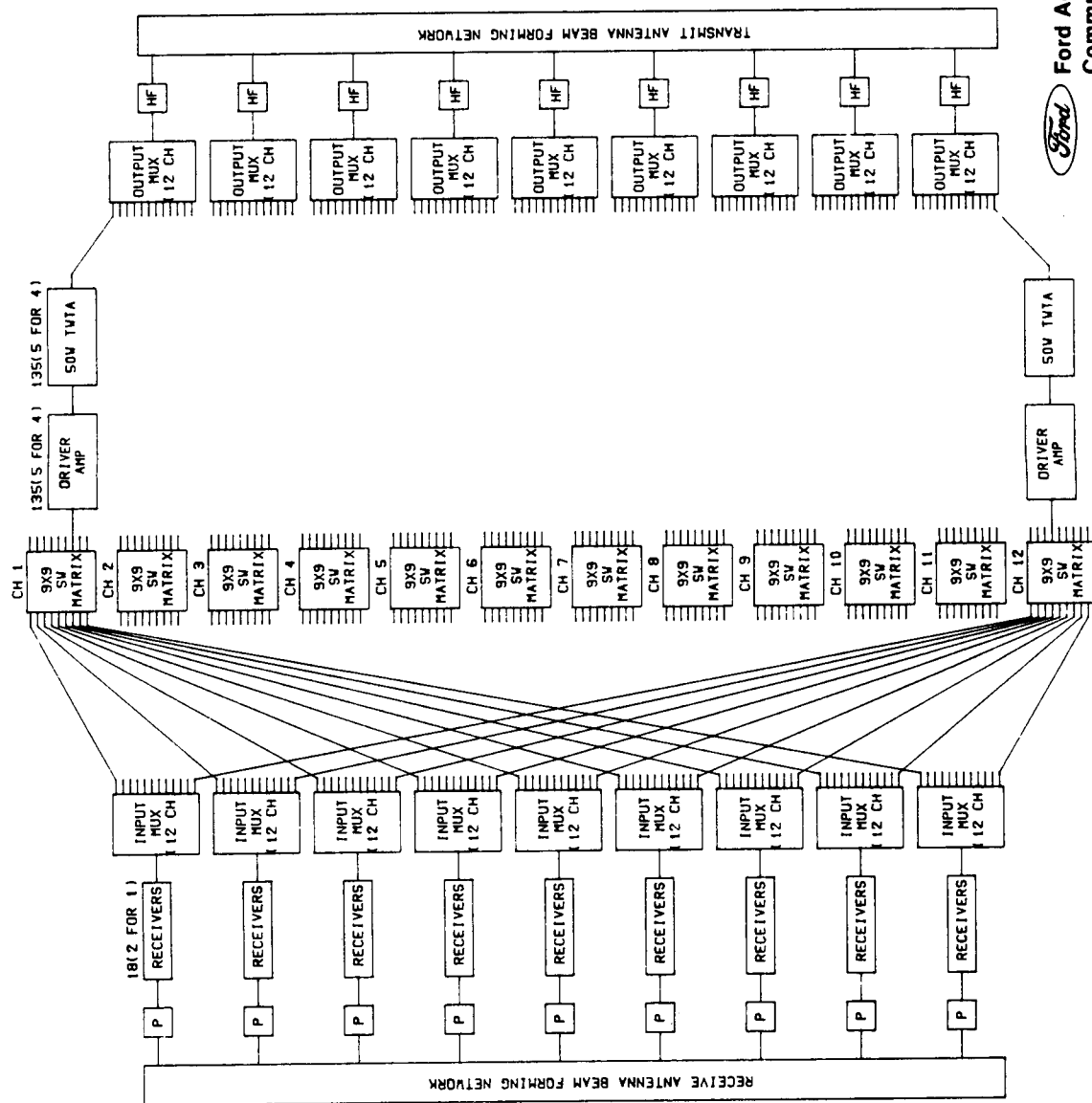


FIGURE 14. - COMPOSITE BLOCK DIAGRAM OF FACC SCENARIO V C-BAND FIXED SATELLITE SERVICE PAYLOAD.



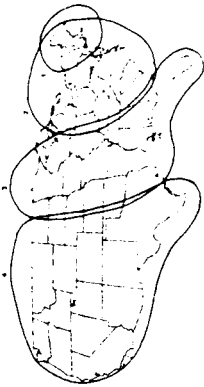
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FIGURE 15. - COMPOSITE BLOCK DIAGRAM OF FACC SCENARIO V KU-BAND FIXED SATELLITE SERVICE PAYLOAD.

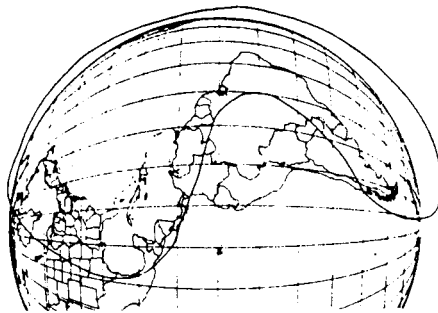
INTER SATELLITE LINKS

- TO/FROM EUROPEAN PLATFORM
 - TO/FROM WESTERN PLATFORM
- POWER: 160 watts
MASS: 110 kg

COMMUNICATIONS - 80 Gb/s



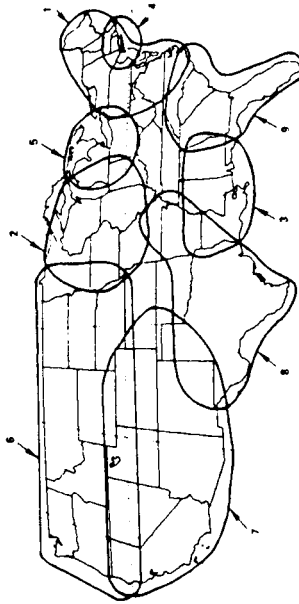
MARITIME PAYLOAD



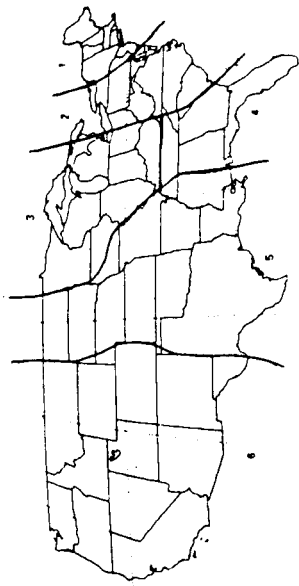
C/L - BAND: 125 VOICE CIRCUITS

POWER: $\frac{650 \text{ watts}}{80 \text{ kg}}$

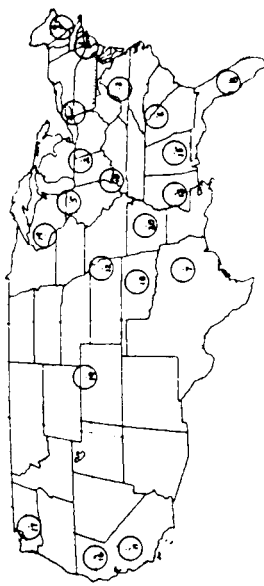
**C-BAND: 48 CHAN OF 36 MHz
(3.5 Gb/s)**



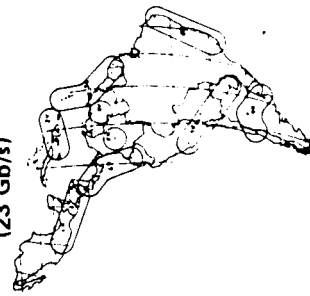
**Ku-BAND: 108 CHAN OF 36 MHz
(7.8 Gb/s)**



**Ka FIXED: 20 BEAM
38 CHAN OF 500 MHz
(38 Gb/s)**



**Ka-SCAN 6 AREAS
18 CHAN of 240 MHz
14 CHANNELS of 500 MHz
(23 Gb/s)**



**C-BAND: 108 CHAN OF 36 MHz
(7.8 Gb/s)**

POWER: $\frac{9,600 \text{ watts}}{3,010 \text{ kg}}$



**COMMUNICATIONS PAYLOAD
OF ~ 3,200 kg
10,400 watts**

FIGURE 16. - SERVICES ALLOCATION FOR FACC SCENARIO VI-A.

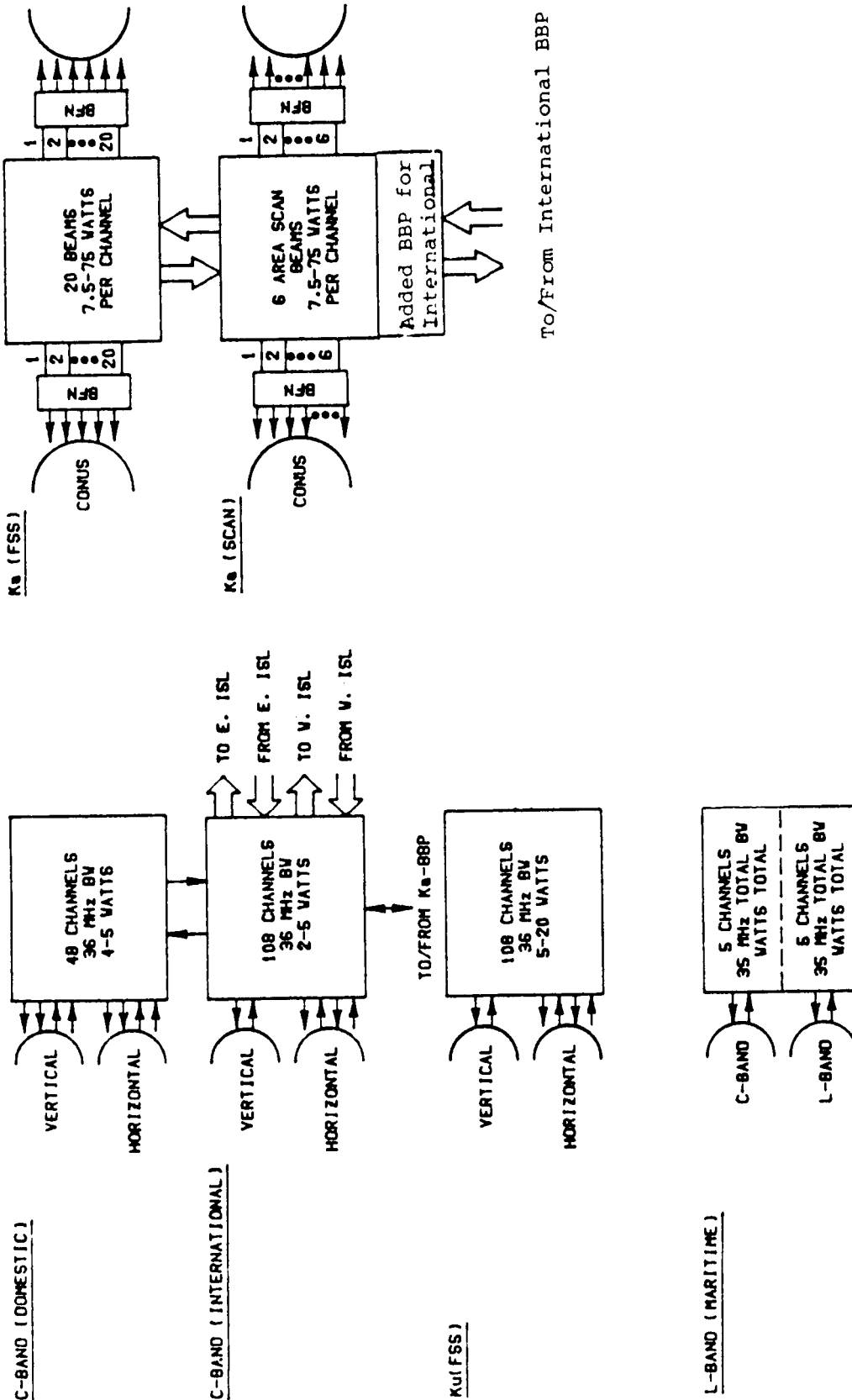
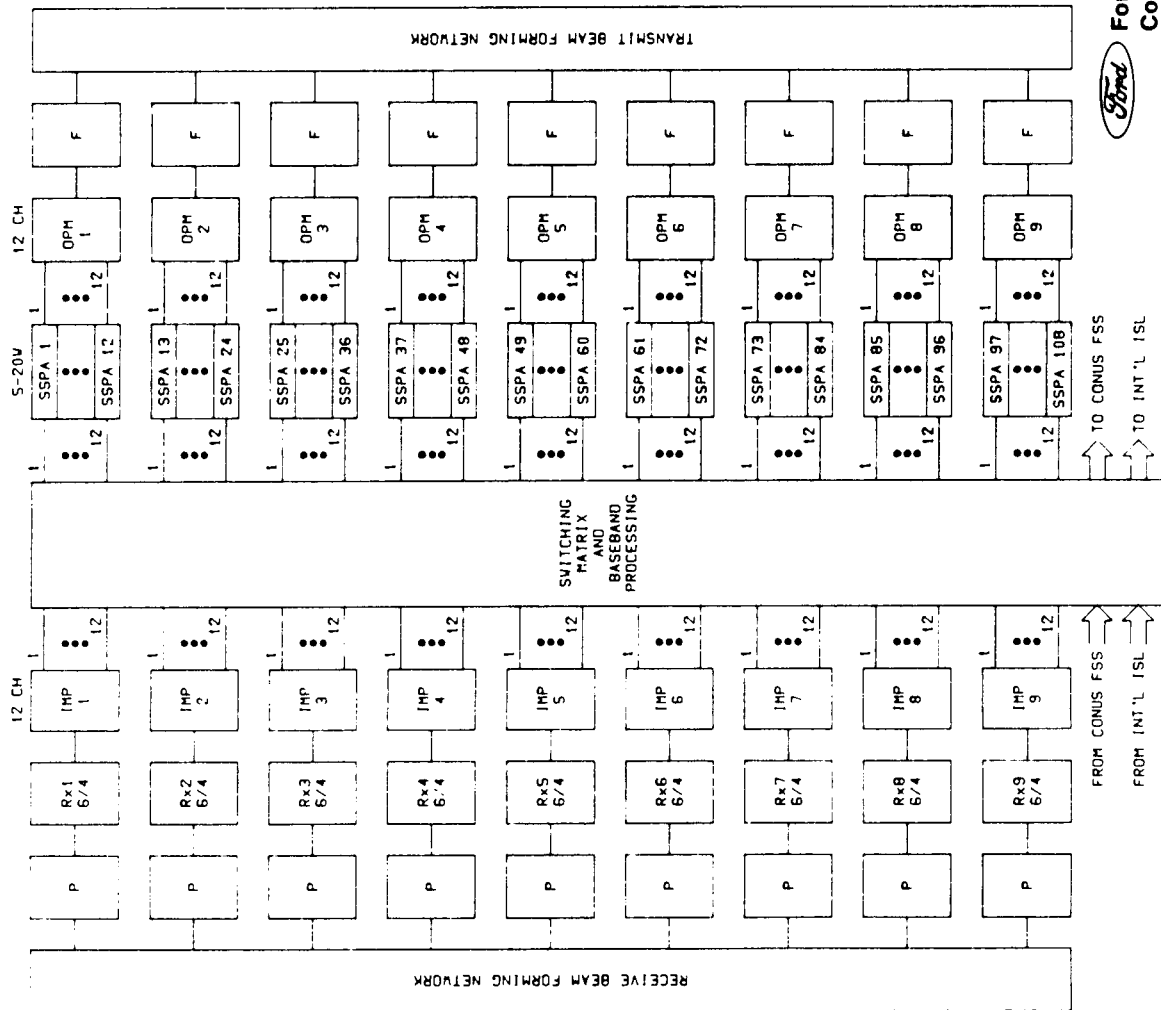


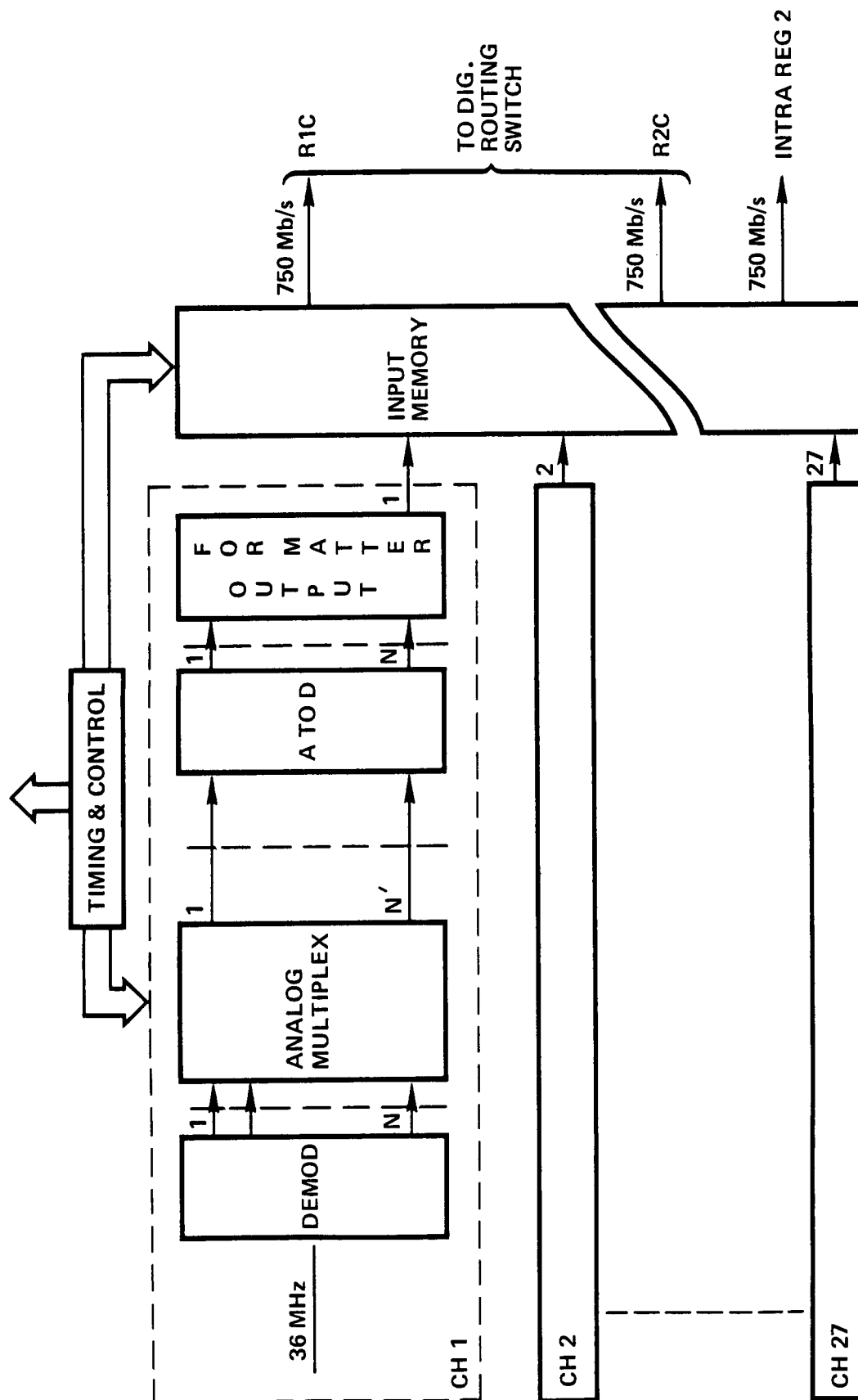
FIGURE 17. - OVERVIEW OF FACC SCENARIO VI-A PAYLOAD.

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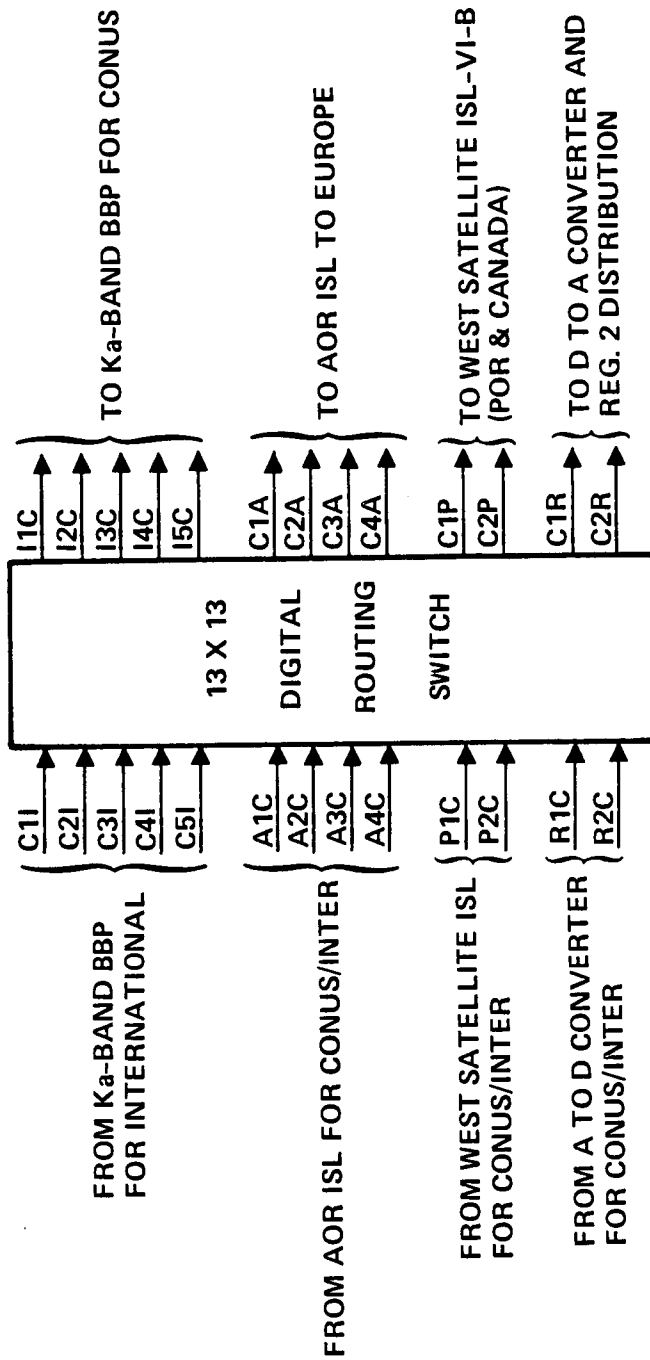
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FIGURE 18. - COMPOSITE BLOCK DIAGRAM OF FACC SCENARIO VI-A C-BAND INTERNATIONAL FIXED SATELLITE SERVICE PAYLOAD.



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FIGURE 19. - BLOCK DIAGRAM OF FACC SCENARIO VI-A C-BAND FSS UPLINK INTERNATIONAL PROCESSOR.



*EACH DATA INPUT/OUTPUT LINE CARRIES 750 Mb/s

FIGURE 20. - FACC SCENARIO VI-A INTERNATIONAL ROUTING SWITCH.

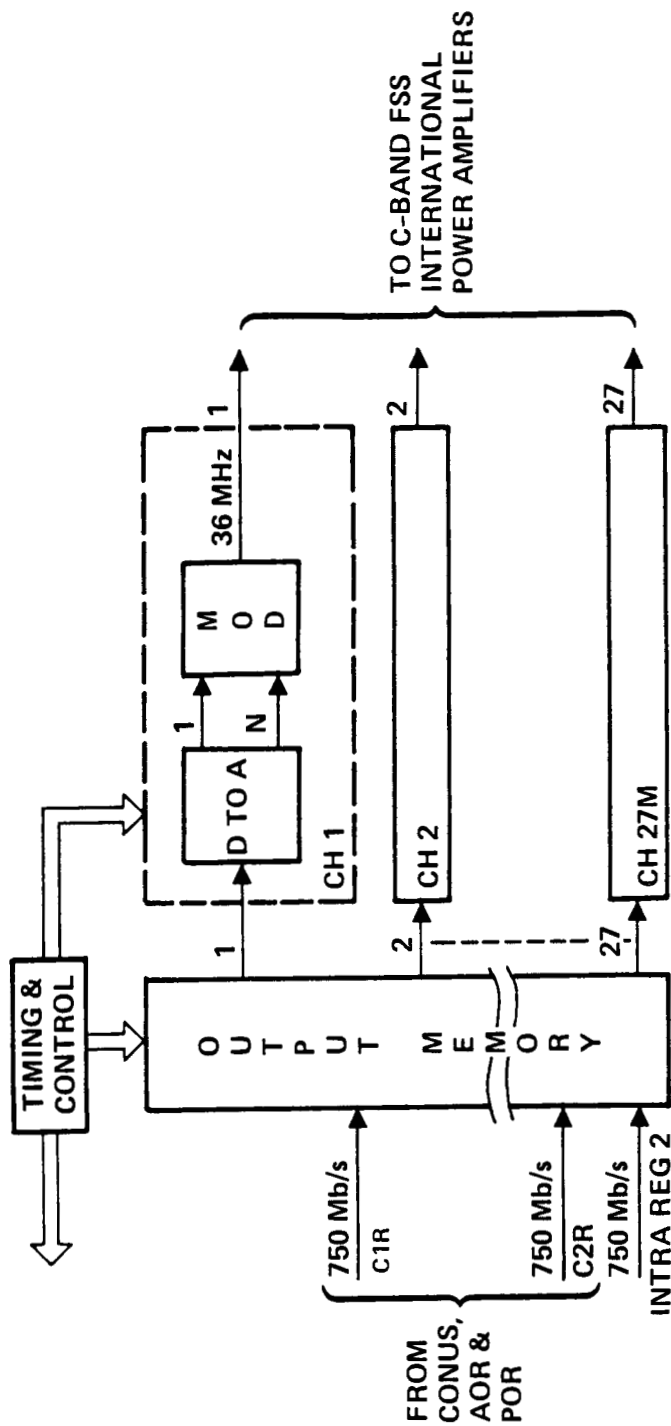


FIGURE 21. - FACCS SCENARIO VI-A C-BAND FSS DOWNLINK INTERNATIONAL PROCESSOR.

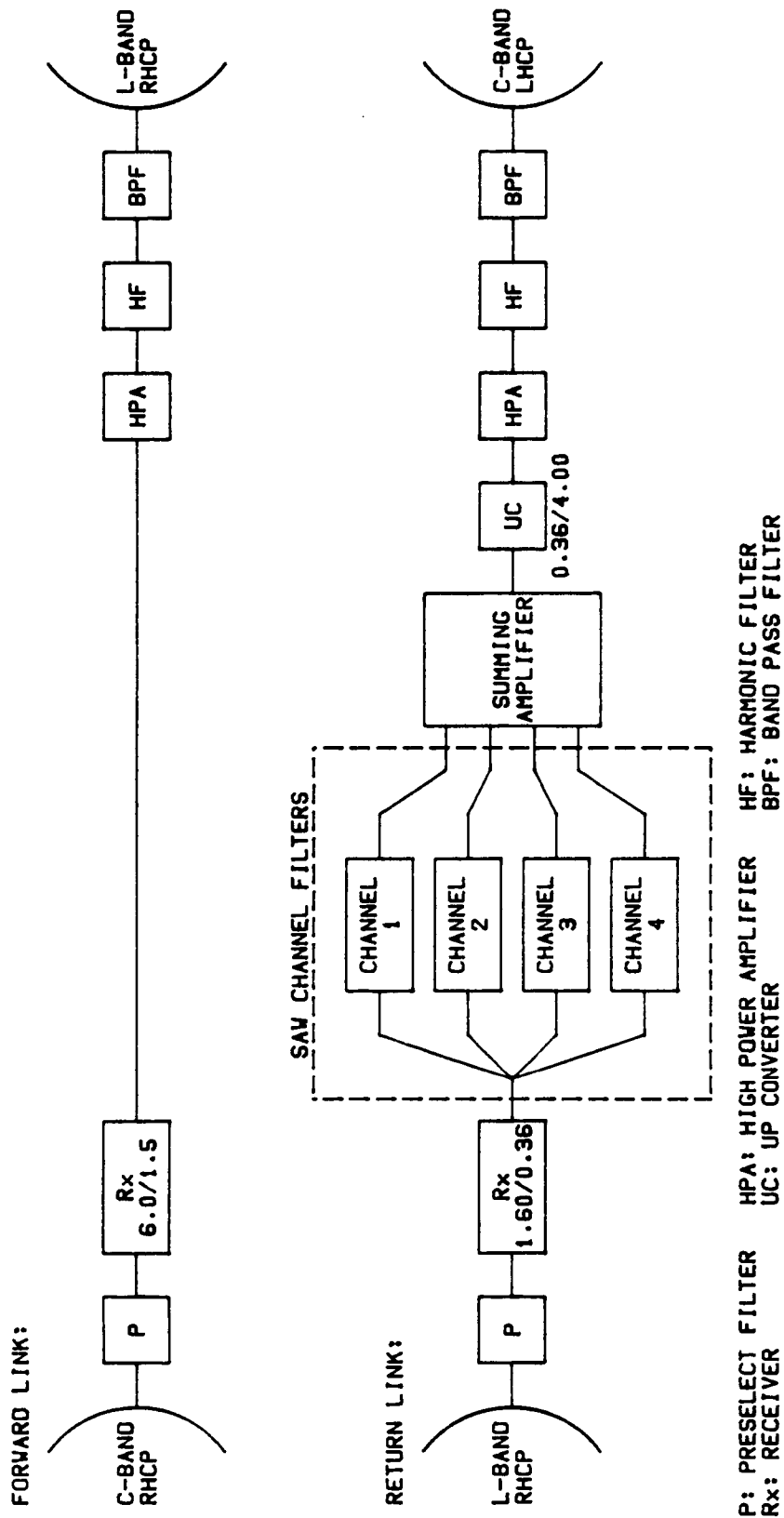


FIGURE 22. - BLOCK DIAGRAM OF FACC SCENARIO VI-A C/L-BAND PAYLOAD.

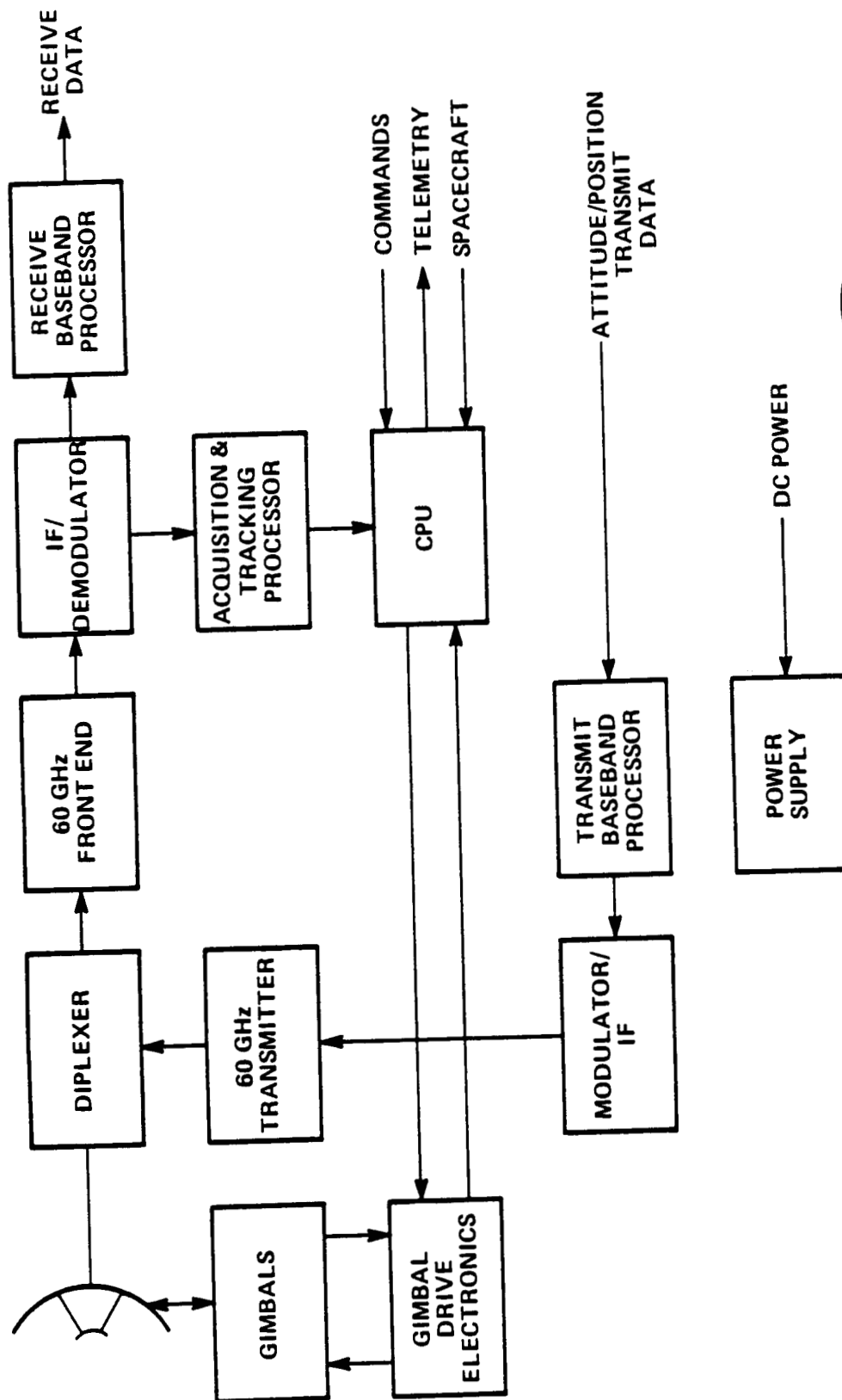


FIGURE 23. - BLOCK DIAGRAM OF FACC SCENARIO VI-A INTERSATELLITE LINK PAYLOAD.

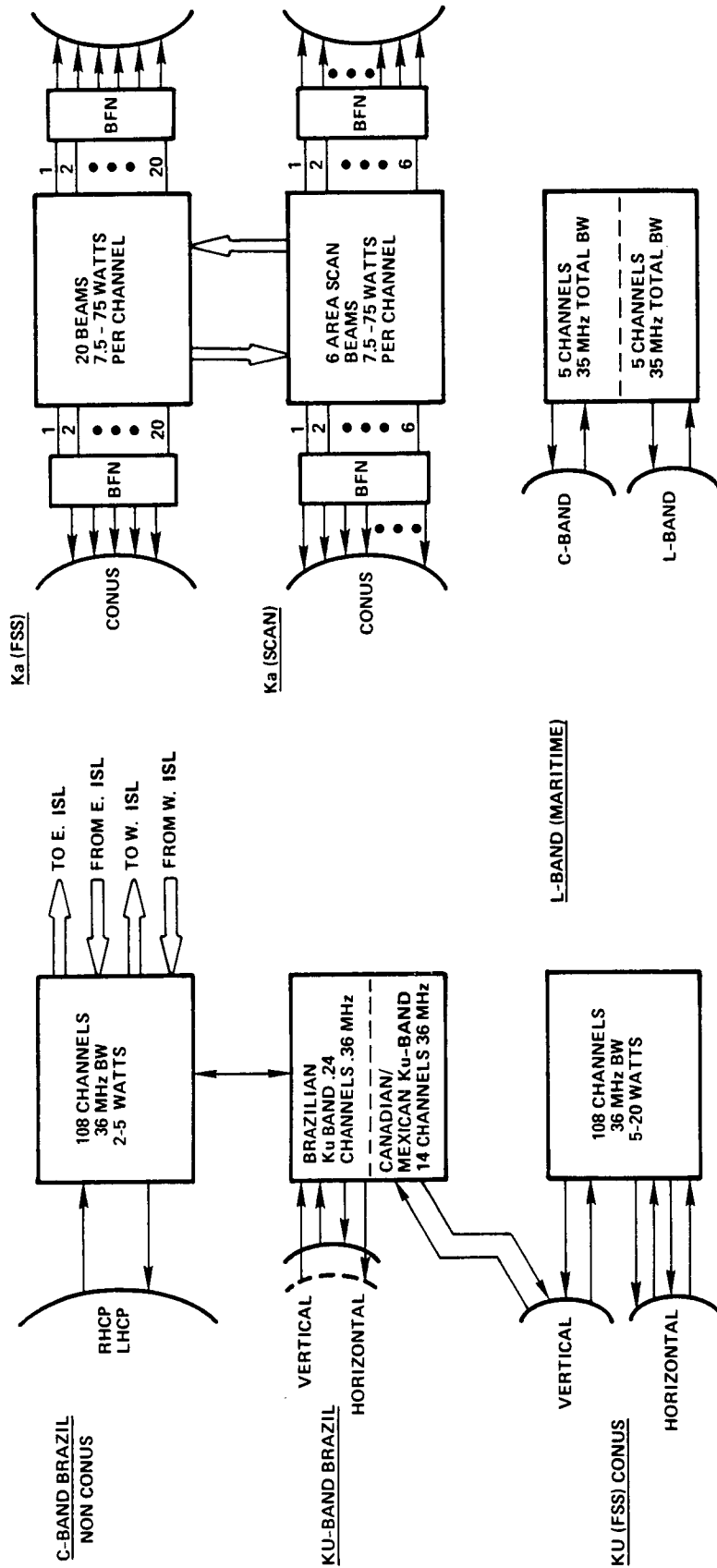


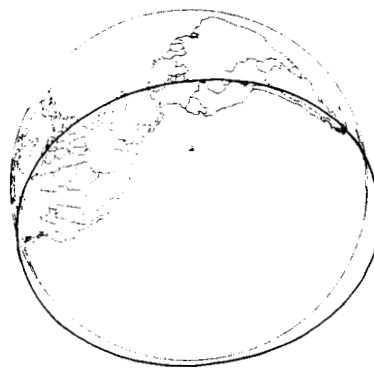
FIGURE 25. - OVERVIEW OF FACC SCENARIO VI-B PAYLOAD.

INTER SATELLITE LINKS

- TO/FROM ASIAN PLATFORM
- TO/FROM EASTERN PLATFORM

POWER: 130 WATTS
MASS: 106 g

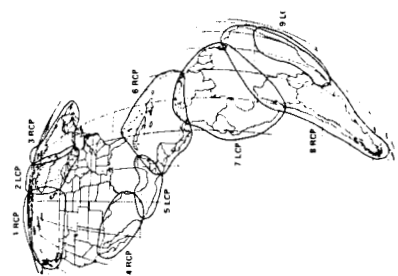
MARITIME PAYLOAD



C/L-BAND: 125 VOICE CIRCUITS
POWER: 650 watts
MASS: 44 kg



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C-BAND: 108 CHAN OF 36 MHz
(7.8 Gb/s)

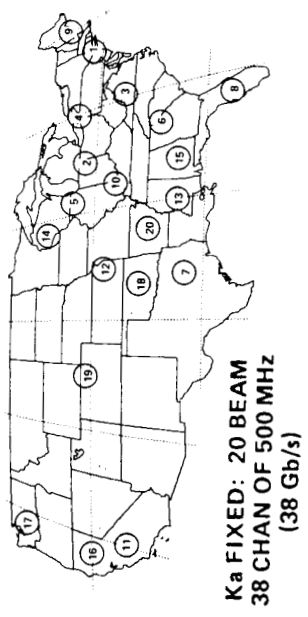


Ku-BAND: 38 CHAN OF 36 MHz POWER: 10,400 watts
(2.7 Gb/s)
MASS: 2,775 kg

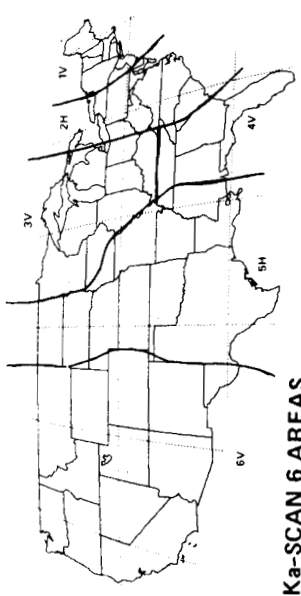


COMMUNICATIONS PAYLOAD
OF 2,925 kg and 11,200 watts

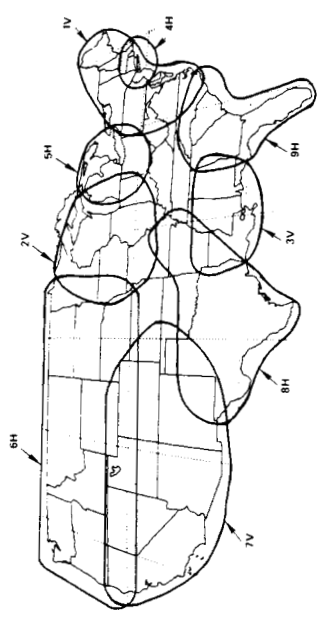
COMMUNICATIONS – 80 Gb/s



Ka FIXED: 20 BEAM
38 CHAN OF 500 MHz
(38 Gb/s)



Ka-SCAN 6 AREAS
18 CHAN OF 240 MHz
14 CHAN OF 500 MHz
(23 Gb/s)



Ku-BAND: 108 CHAN OF 36 MHz
(7.8 Gb/s)

FIGURE 24. - SERVICES ALLOCATION FOR FACC SCENARIO VI-B.

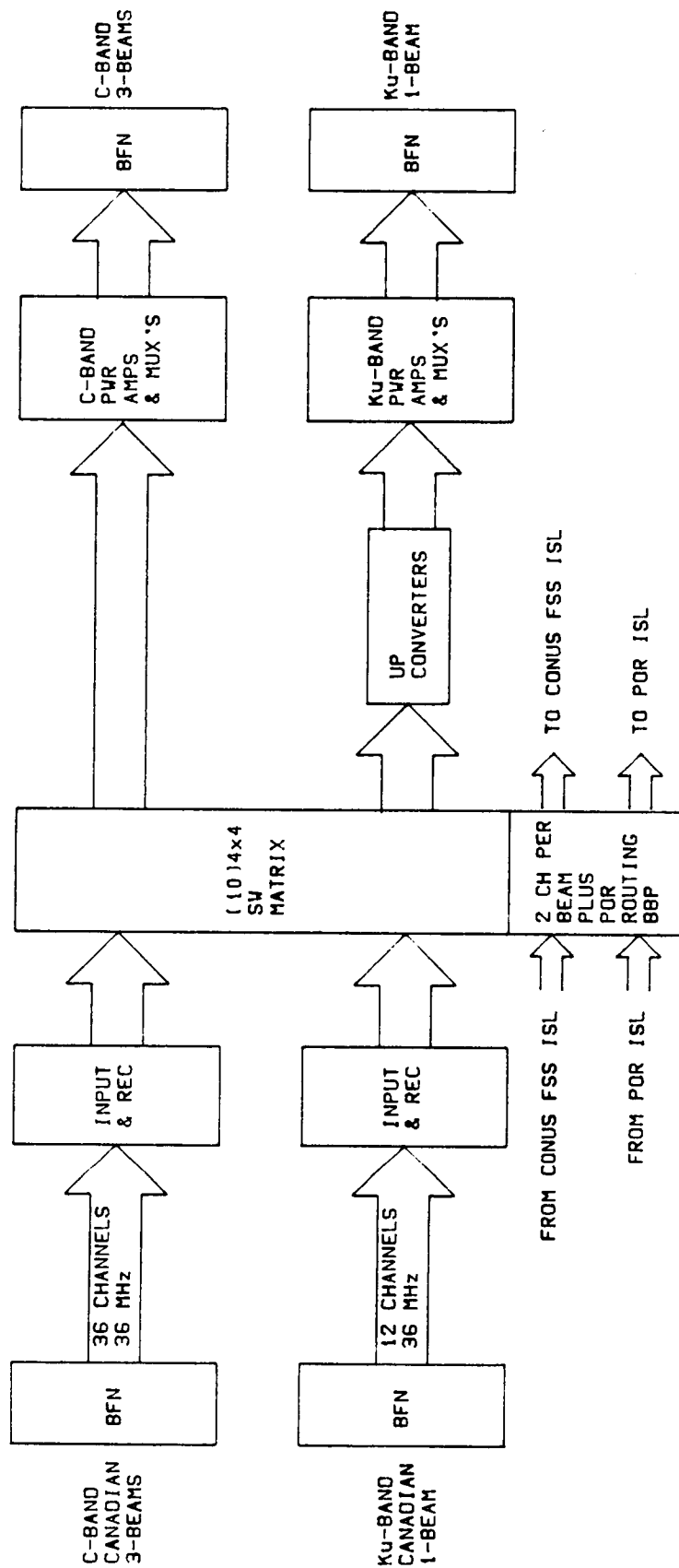
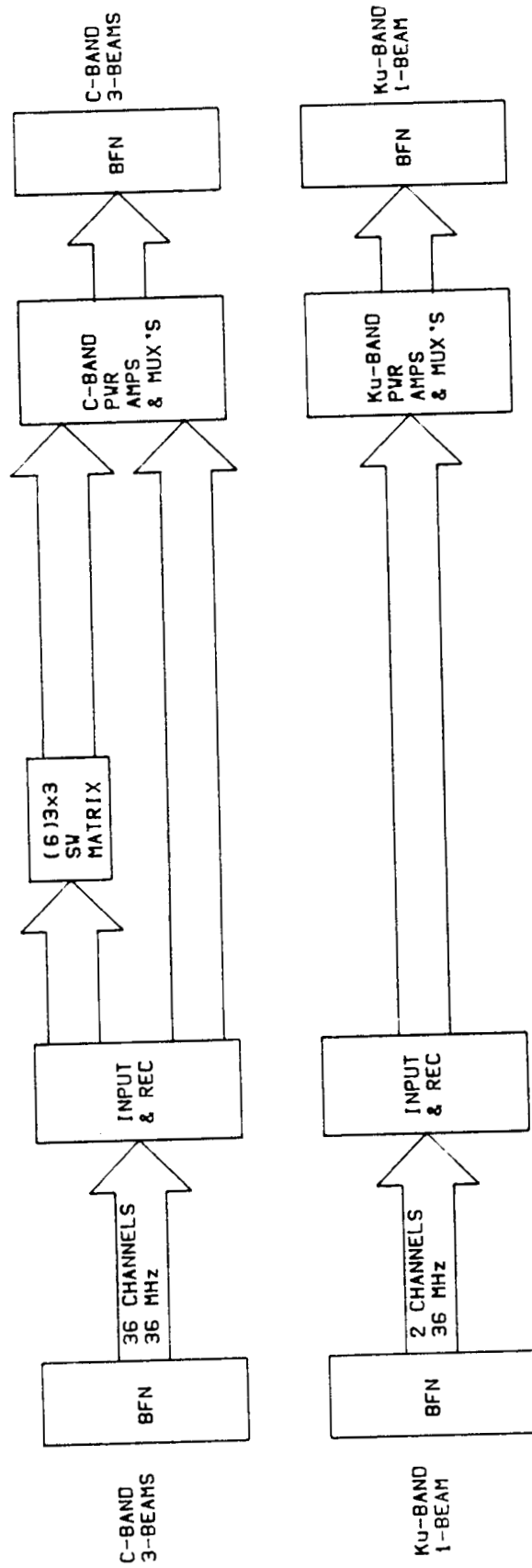


FIGURE 26. - BLOCK DIAGRAM OF FACC CANADIAN DOMESTIC, REGIONAL, AND INTERNATIONAL PAYLOAD.



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FIGURE 27. - BLOCK DIAGRAM OF FACC MEXICAN/CARIBBEAN DOMESTIC AND REGIONAL PAYLOAD.

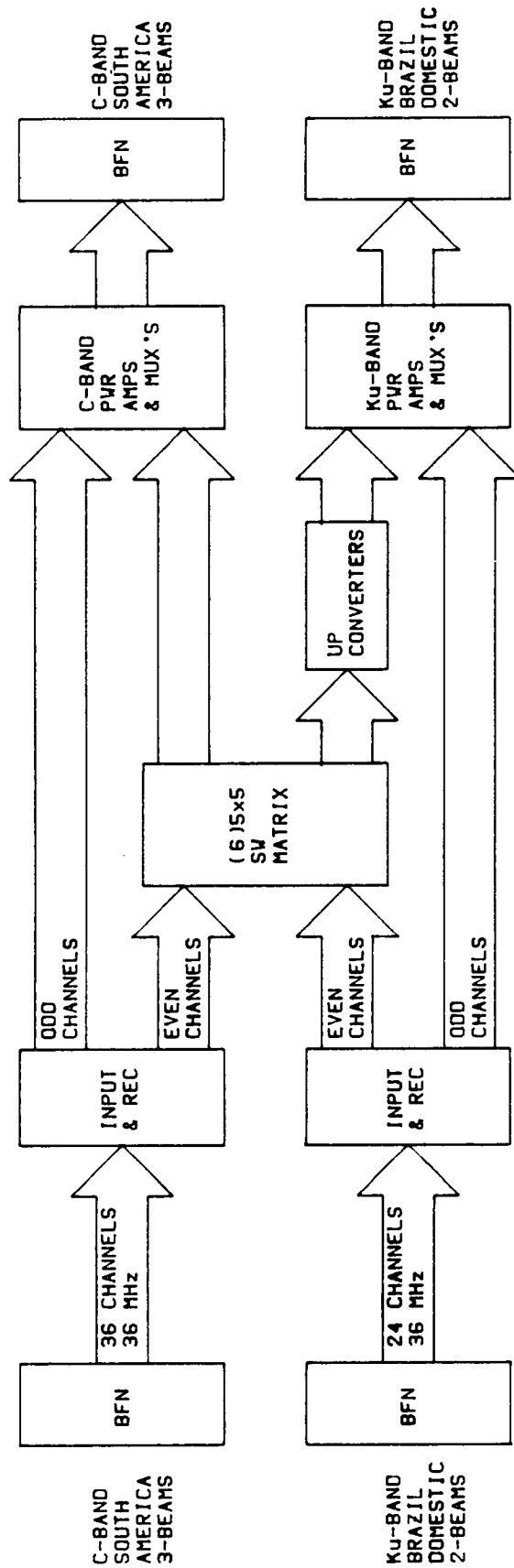


FIGURE 28. - BLOCK DIAGRAM OF FACC SOUTH AMERICAN DOMESTIC AND REGIONAL PAYLOAD.

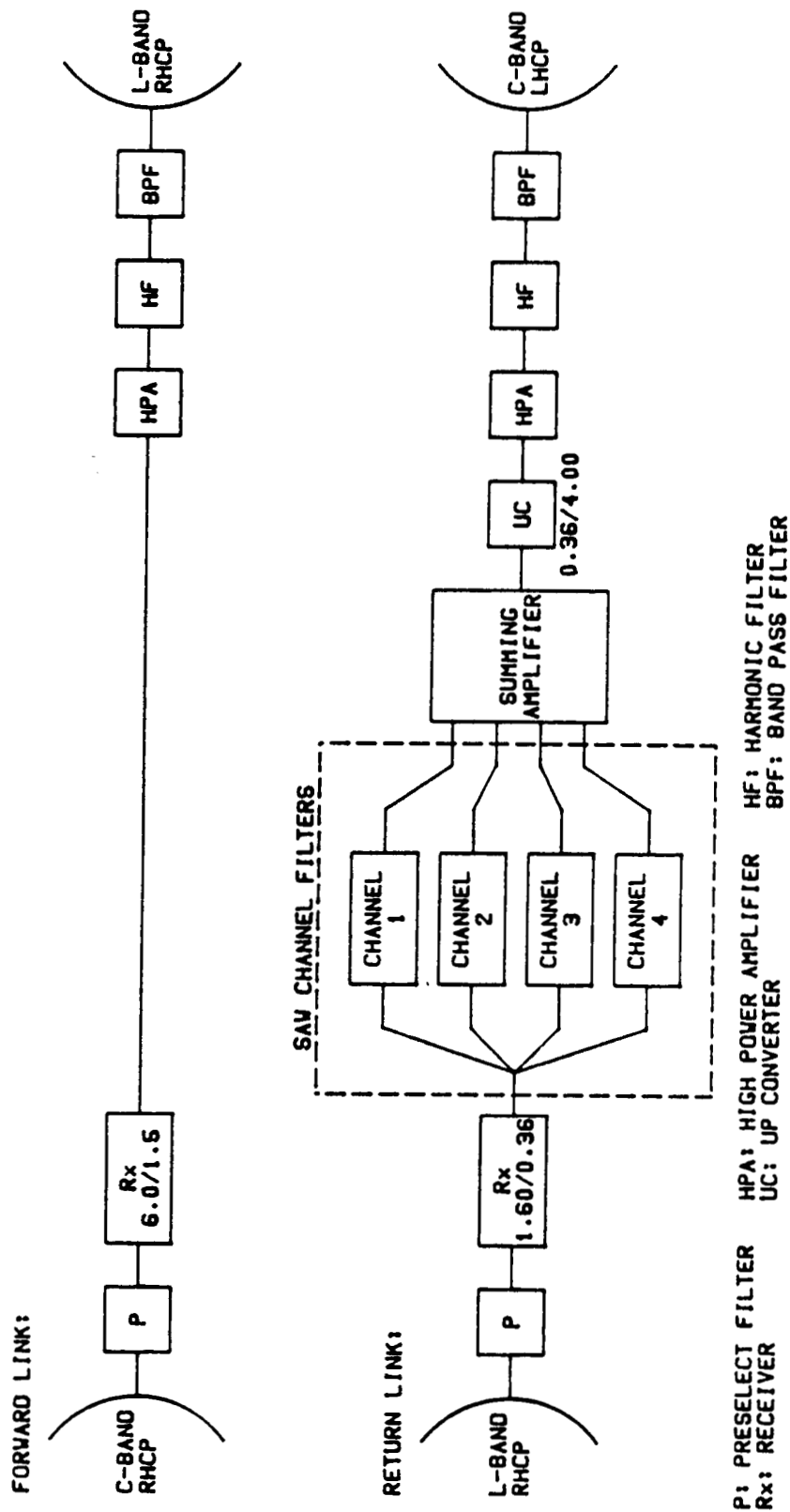
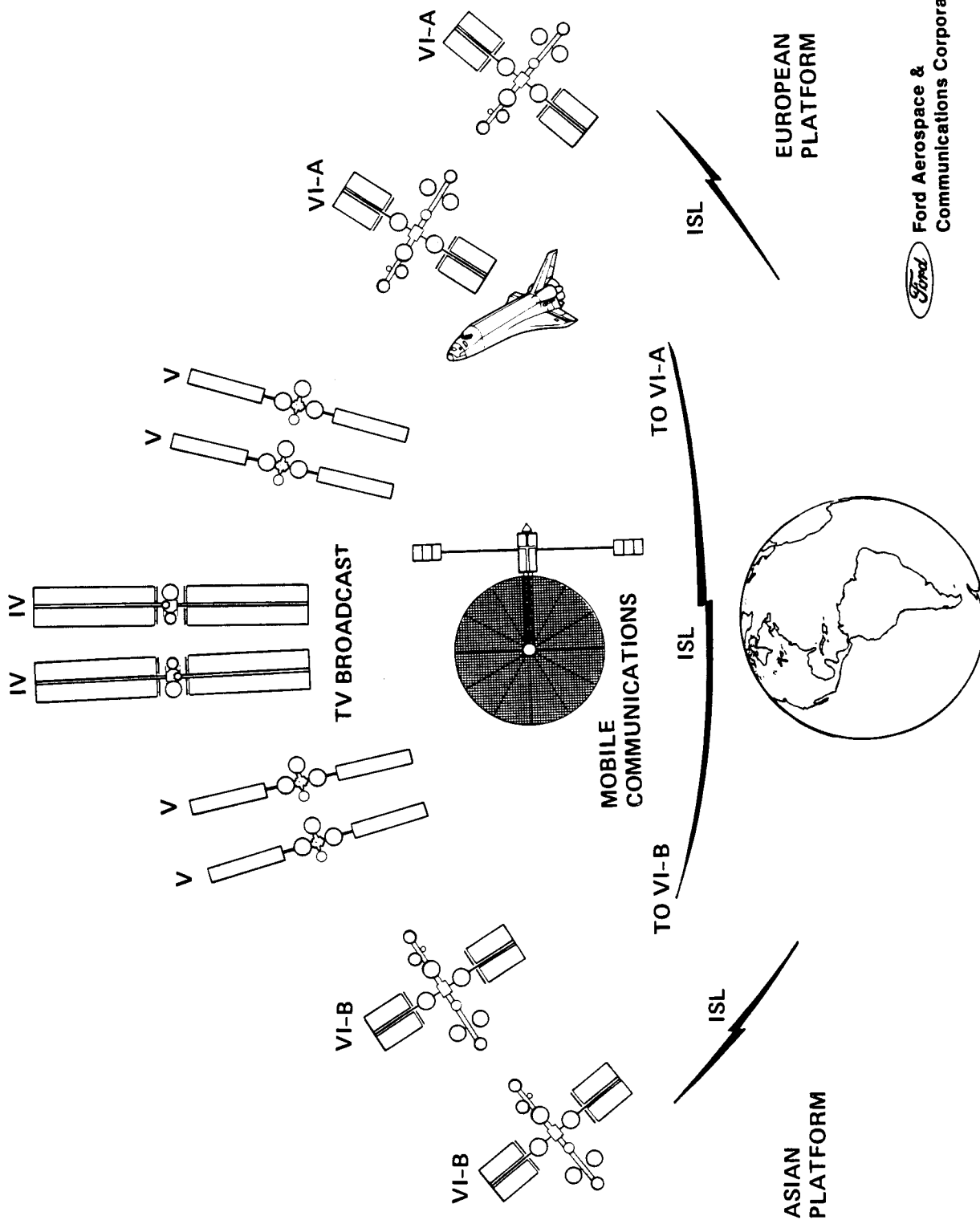


FIGURE 30. - BLOCK DIAGRAM OF FACC SCENARIO VI-B C/L-BAND EASTERN PACIFIC MARITIME PAYLOAD.



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FIGURE 31. - FACC's FUTURE NETWORK OF PLATFORMS FOR REGION 2.

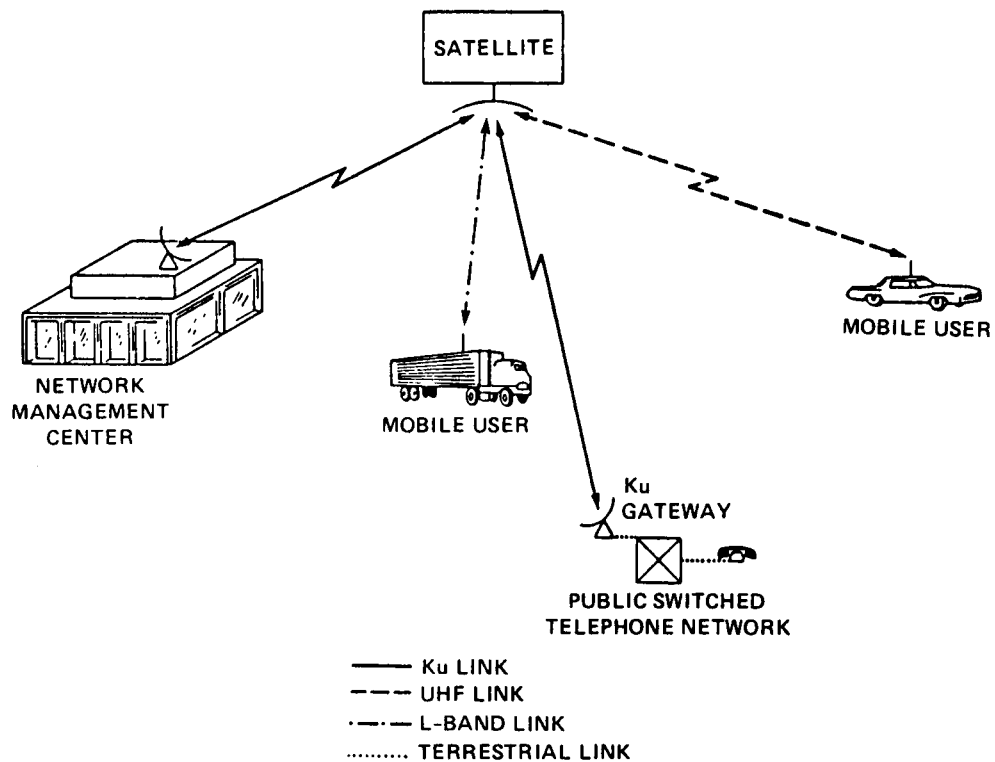
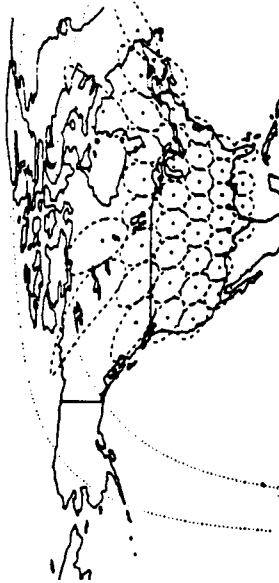


FIGURE 32. - RCA PAYLOAD CONCEPT 1 (LMSS NETWORK) CONFIGURATION.

MOBILE RADIO TELEPHONE (VOICE)

200,000 USERS
4508 CHANNELS

4 MHz UHF BANDWIDTH
7 KHz CHANNEL SPACING
3 KHz IF



CONUS

27 BEAMS (.8°)
140 CHANNELS/BEAM
3780 TOTAL CHANNELS
1890 WATTS RF

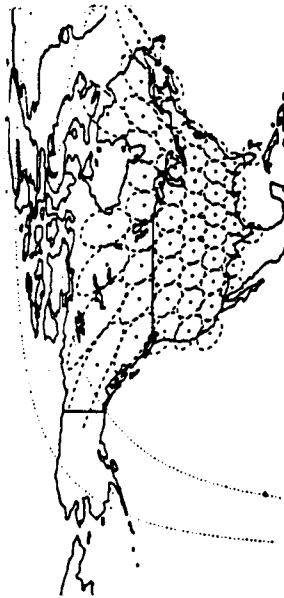
CANADA

13 BEAMS (.8°)
56 CHANNELS/BEAM
728 TOTAL CHANNELS
728 WATTS RF

DIGITAL DATA SERVICES (PAGING, DISPATCH)

1,100,000 USERS
662 CHANNELS

6 MHz L-BAND BANDWIDTH
10 KHz CHANNEL SPACING
3 KBPS RATE



GATEWAY

50 MHz Ku BANDWIDTH
SINGLE HORN
50-100 TERMINALS

CONUS

35 BEAMS (.7°)
16 CHANNELS/BEAM
560 TOTAL CHANNELS
1120 WATTS RF

CANADA

17 BEAMS (.7°)
6 CHANNELS/BEAM
102 TOTAL CHANNELS
204 WATTS RF

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FIGURE 33. - SCENARIO DESCRIPTION OF RCA PAYLOAD CONCEPT 1. PAYLOAD MASS, ~1172 KG; PAYLOAD POWER, ~8081 W.

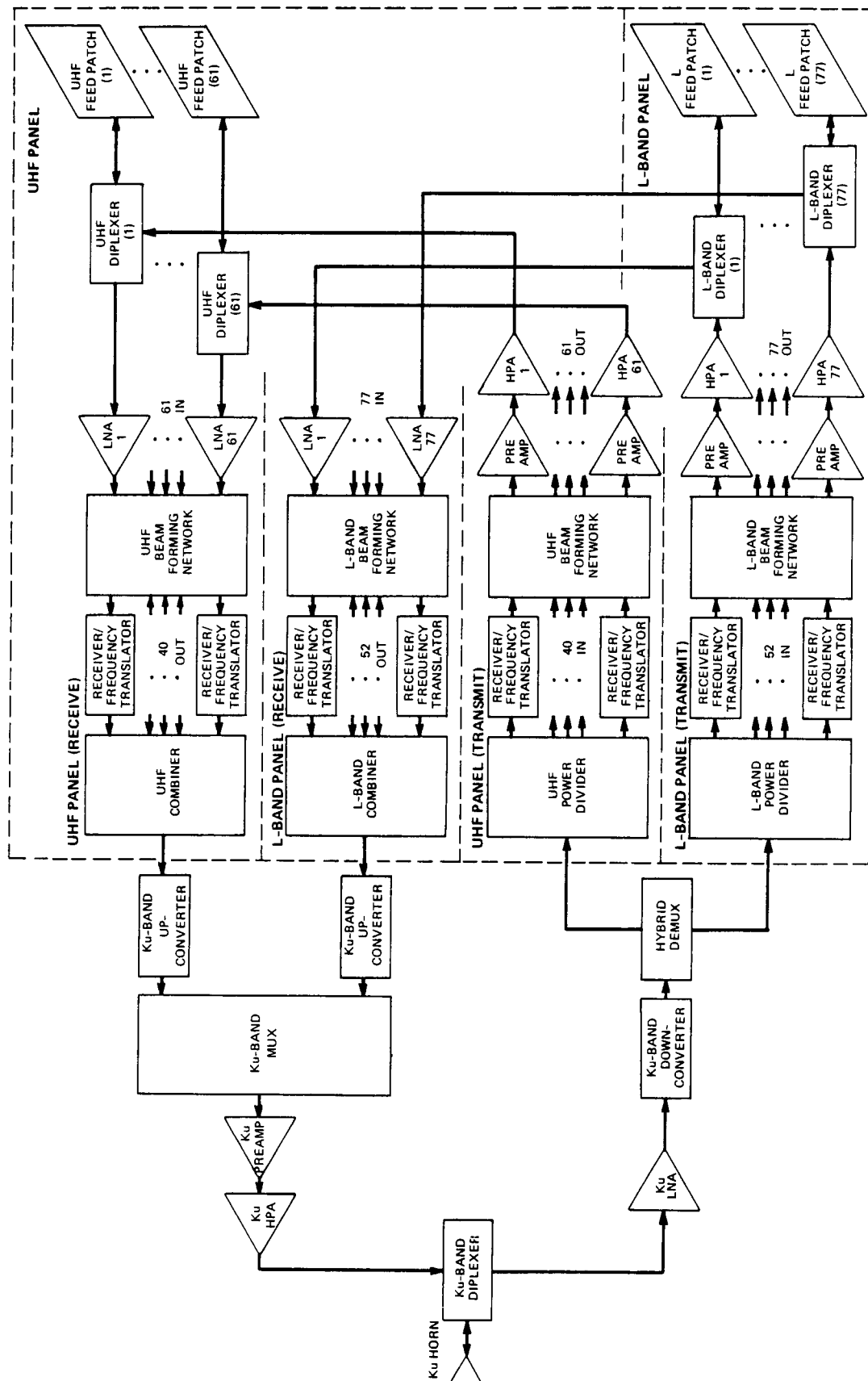
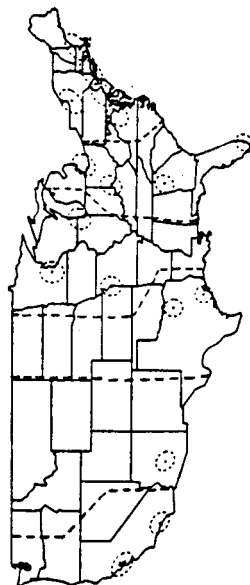
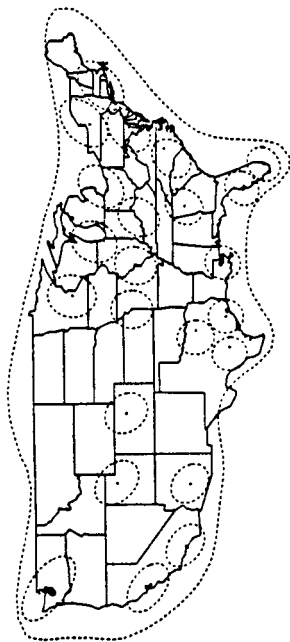


FIGURE 34. - BLOCK DIAGRAM OF RCA PAYLOAD CONCEPT 1.

TRUNKING VIA C, Ka

CUSTOMER PREMISES SERVICE VIA Ku, Ka



C-BAND

- 23 0.5° SPOT + CONUS
- 109 CHANNELS (36 MHz)
- 60 MBPS/CHANNEL

Ku-BAND

- 23 0.5° SPOT + CONUS
- 76 CHANNELS (36 MHz)
- 60 MBPS/CHANNEL

Ka-BAND

- 17 0.25° FIXED SPOT
- 6 0.25° SCAN SPOT
- 326 CHANNELS (36 MHz)

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FIGURE 35. - SCENARIO DESCRIPTION OF RCA PAYLOAD CONCEPT 2 (FIXED SATELLITE SERVICE WITH CAPACITY EQUAL TO 20 PERCENT OF DEMAND). PAYLOAD MASS, ~2144 kg; PAYLOAD POWER, ~15 508 W; SYSTEM CAPACITY, 30.7 Gb/s.

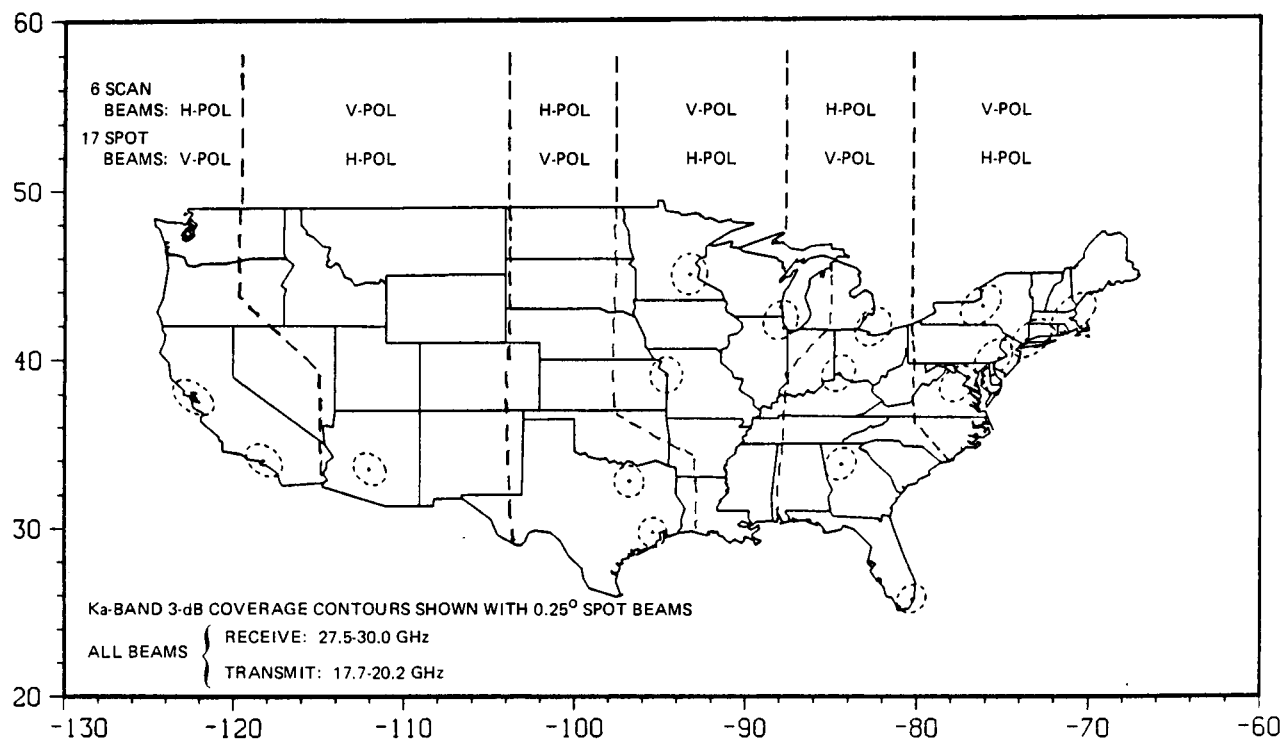


FIGURE 36. - Ka-BAND 3-dB COVERAGE CONTOURS FOR RCA PAYLOAD CONCEPT 2.

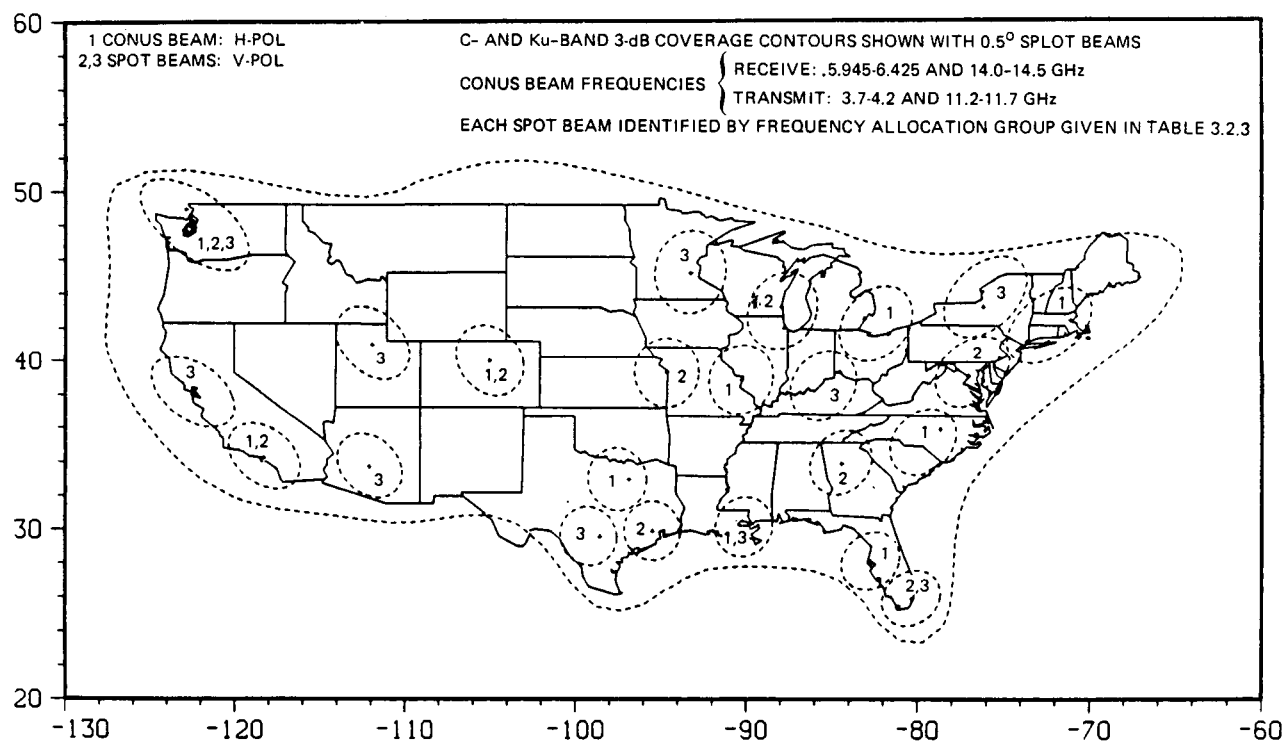


FIGURE 37. - C- AND Ku-BAND 3-dB COVERAGE CONTOURS FOR RCA PAYLOAD CONCEPT 2.

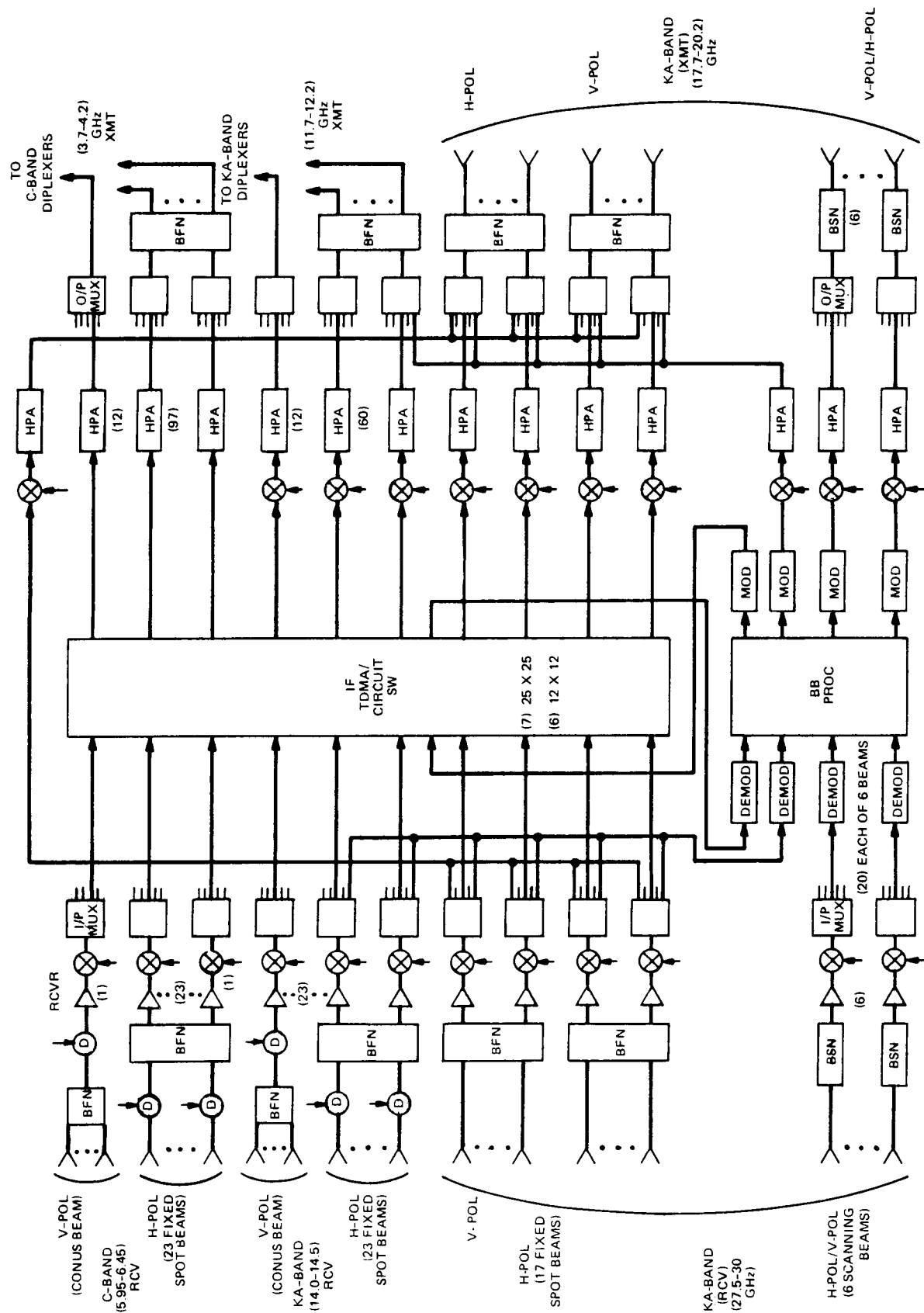
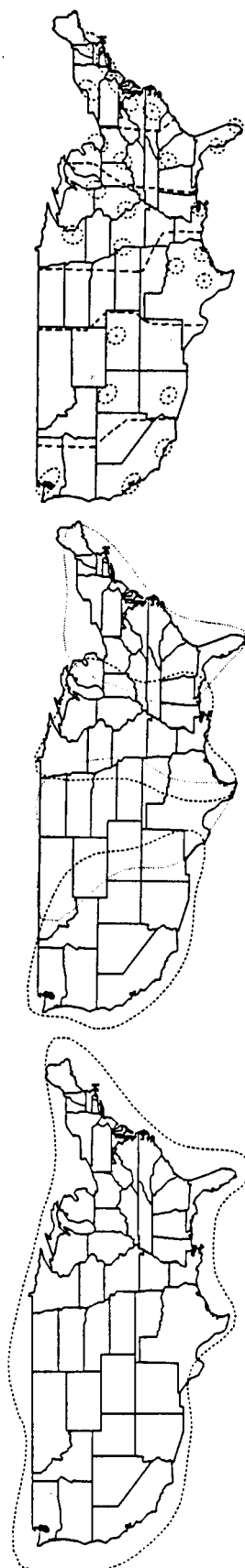
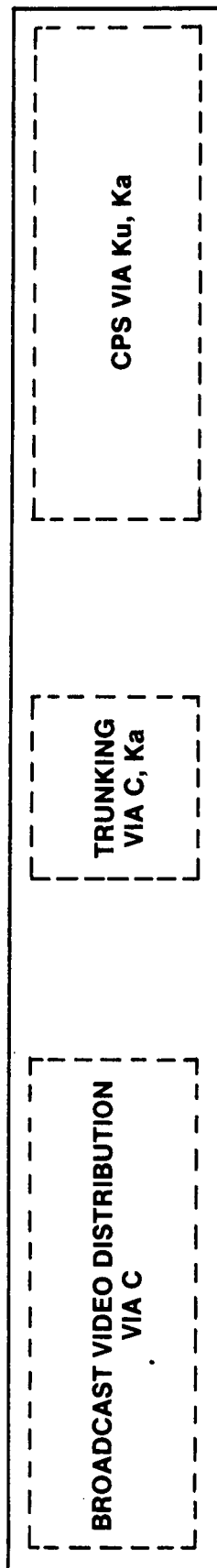


FIGURE 38. - BLOCK DIAGRAM FOR RCA PAYLOAD CONCEPT 2.



C-BAND

CONUS BEAM
24 CHANNELS (36 MHz)
60 MBPS/CHANNEL

Ku-BAND

1/4 CONUS BEAMS
41 CHANNELS (36 MHz)
60 MBPS/CHANNEL

Ka-BAND

25 0.25° FIXED SPOT
6 0.25° SCAN SPOT
308 CHANNELS (36 MHz)

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FIGURE 39. - SCENARIO DESCRIPTION FOR RCA PAYLOAD CONCEPT 3 (FIXED SATELLITE SERVICE WITH CAPACITY EQUAL TO 13 PERCENT OF DEMAND AND 10 PERCENT CONUS VIDEO DISTRIBUTION). PAYLOAD MASS, ~1508 KG; PAYLOAD POWER, ~12 290 W; SYSTEM CAPACITY, 22.4 Gb/s.

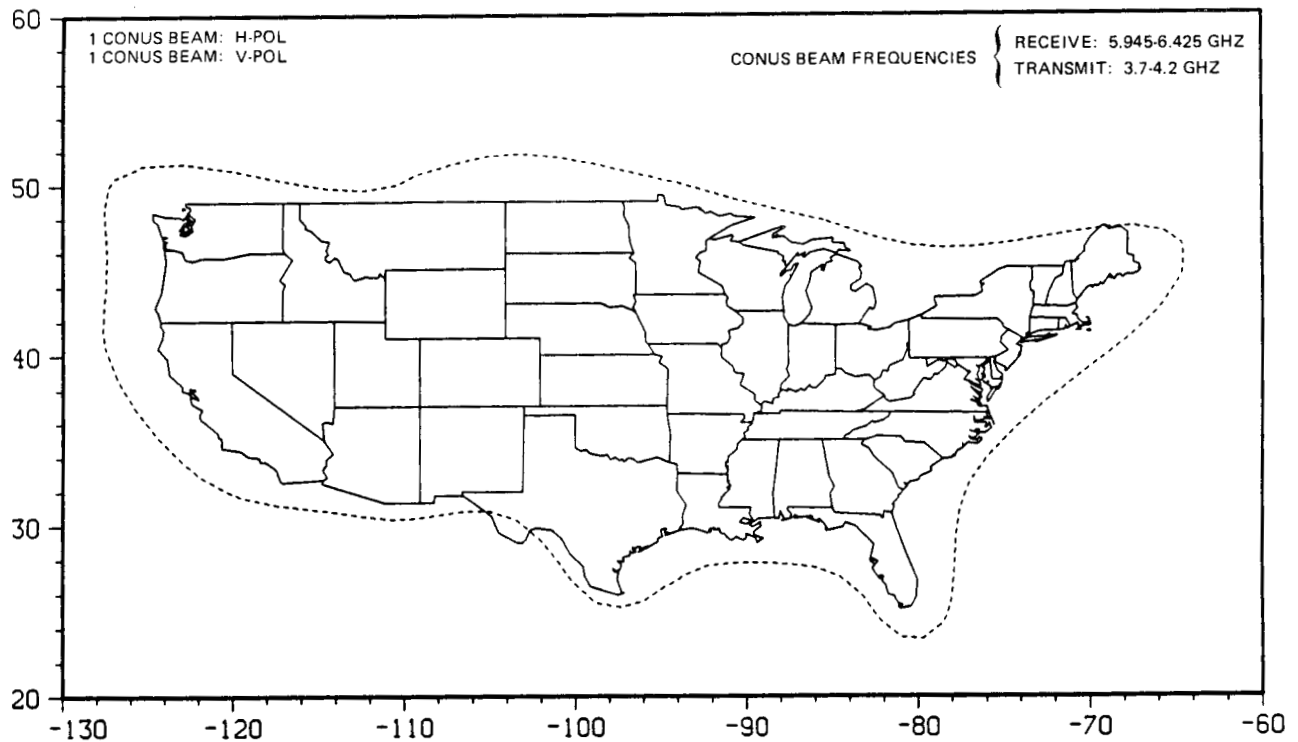


FIGURE 40. - C-BAND 3-DB COVERAGE CONTOURS FOR RCA PAYLOAD CONCEPT 3.

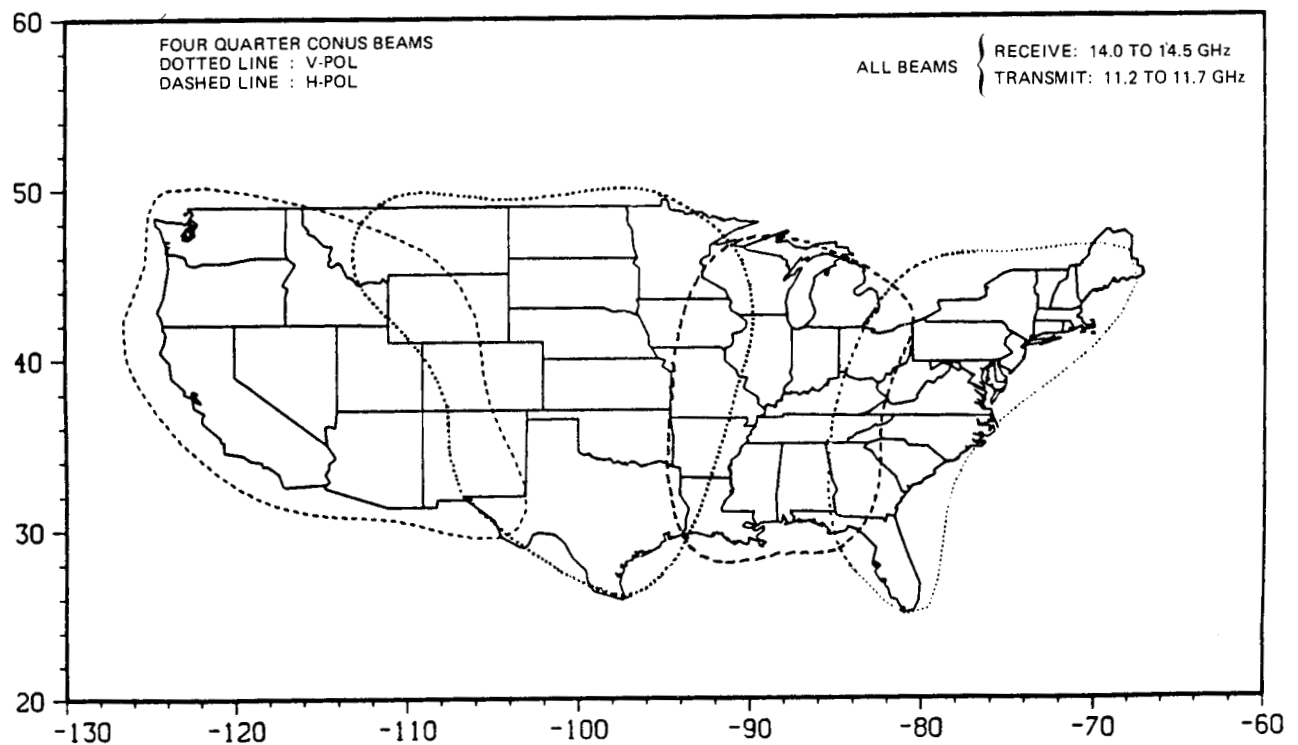


FIGURE 41. - KU-BAND 3-DB COVERAGE CONTOURS FOR RCA PAYLOAD CONCEPT 3.

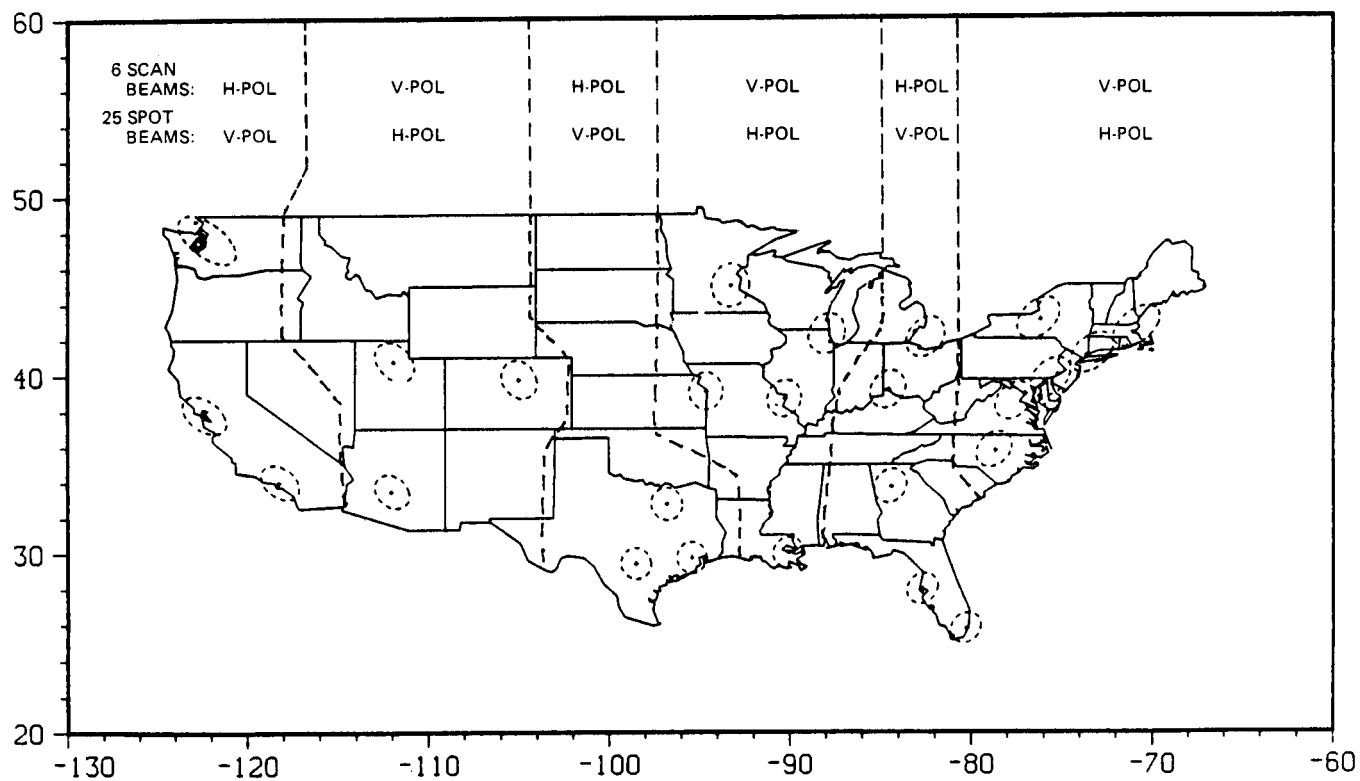


FIGURE 42. - KA-BAND 3-DB COVERAGE CONTOURS FOR RCA PAYLOAD CONCEPT 3.

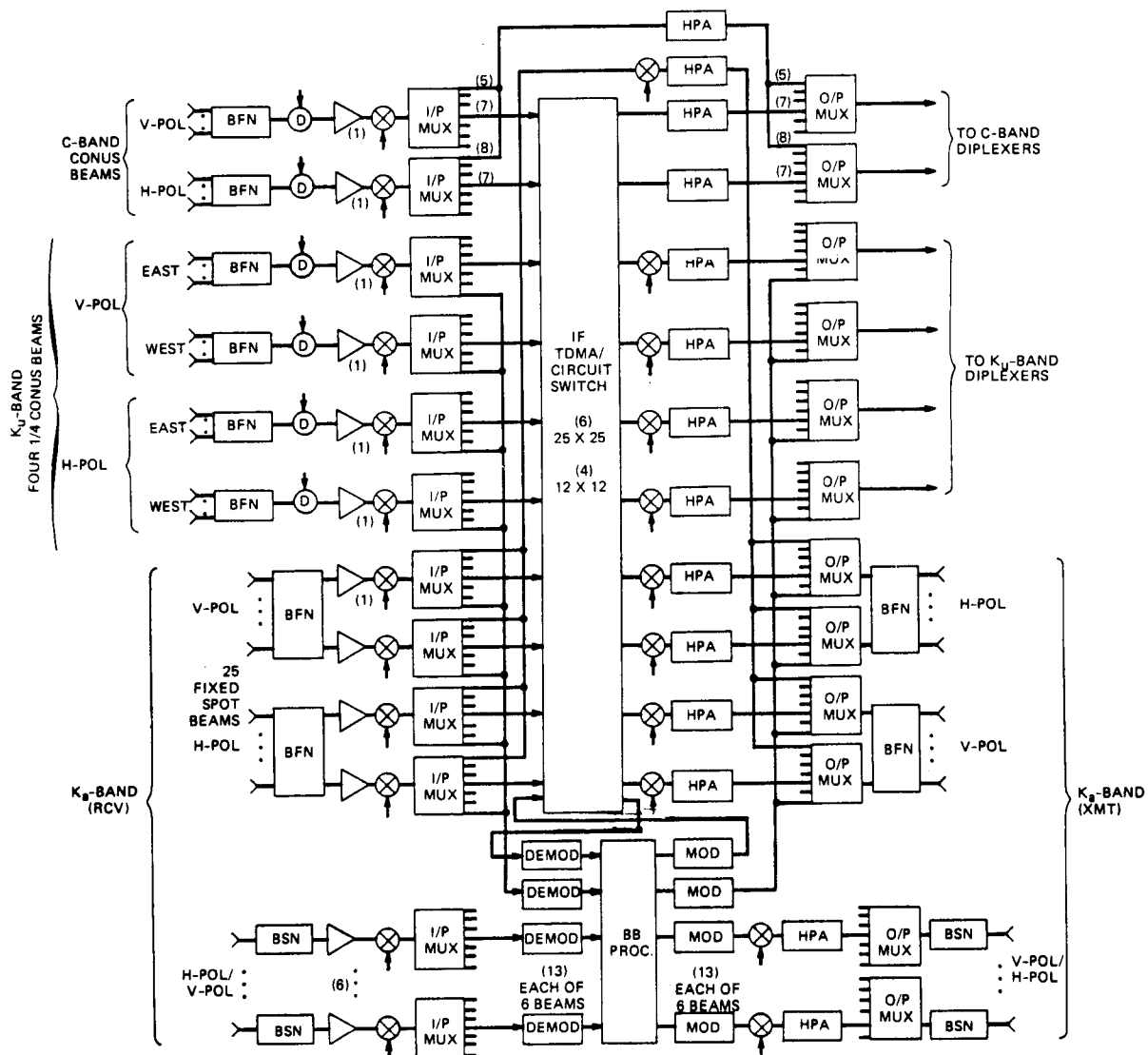
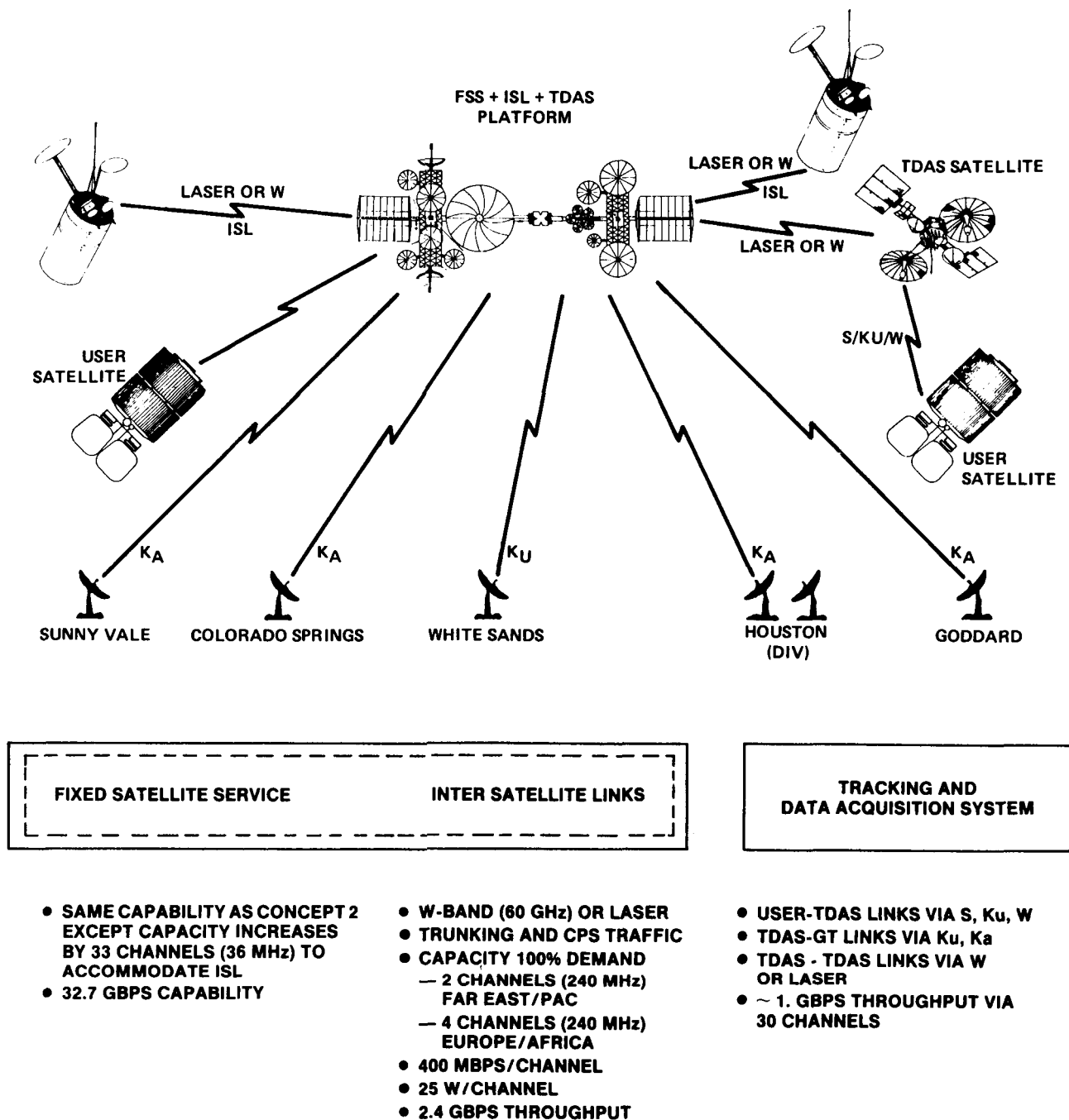


FIGURE 43. - BLOCK DIAGRAM FOR RCA PAYLOAD CONCEPT 3.



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FIGURE 44. - SCENARIO DESCRIPTION FOR RCA PAYLOAD CONCEPT 4 (FIXED SATELLITE SERVICE WITH CAPACITY EQUAL TO 20 PERCENT OF DEMAND, INTERSATELLITE LINKS, AND TRACKING AND DATA ACQUISITION SYSTEM). PAYLOAD MASS, ~3155 KG; PAYLOAD POWER, ~18 946 W; SYSTEM CAPACITY, 36.5 GB/s.

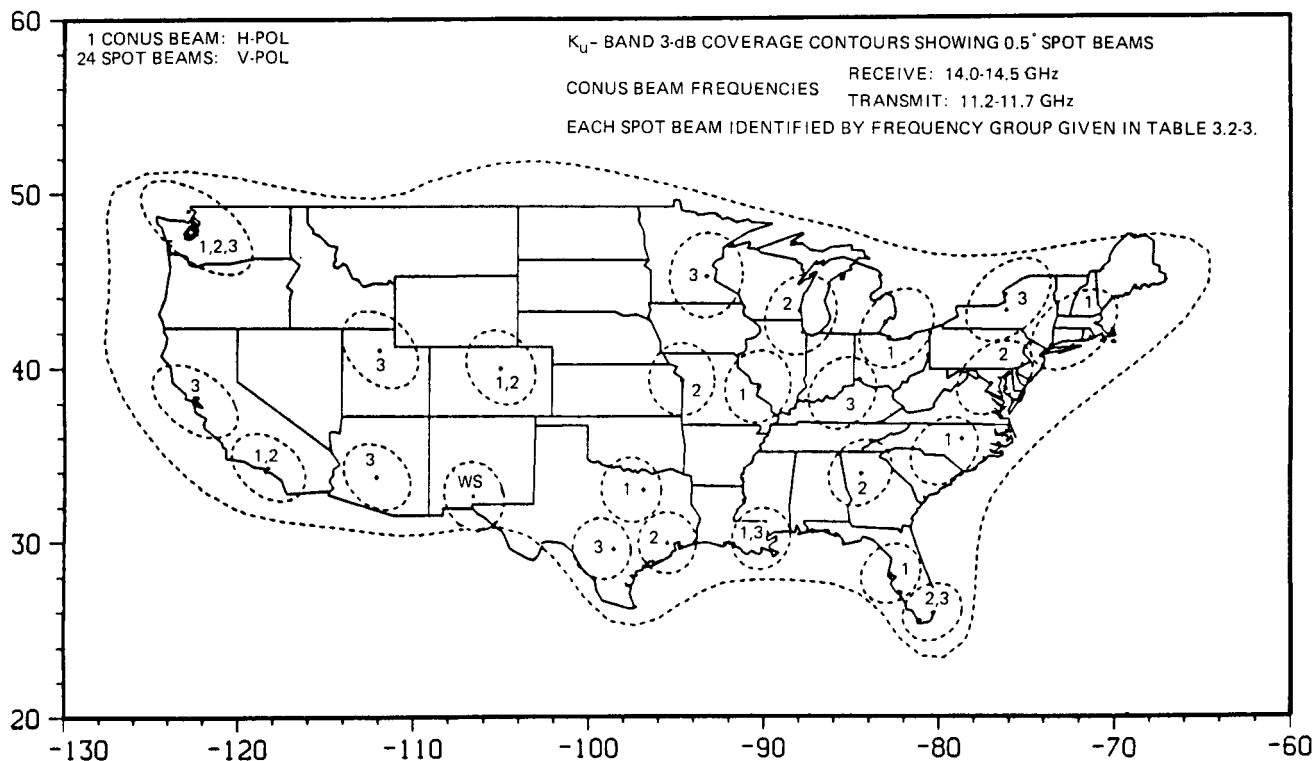


FIGURE 45. - K_U-BAND 3-dB COVERAGE CONTOURS FOR RCA PAYLOAD CONCEPT 4.

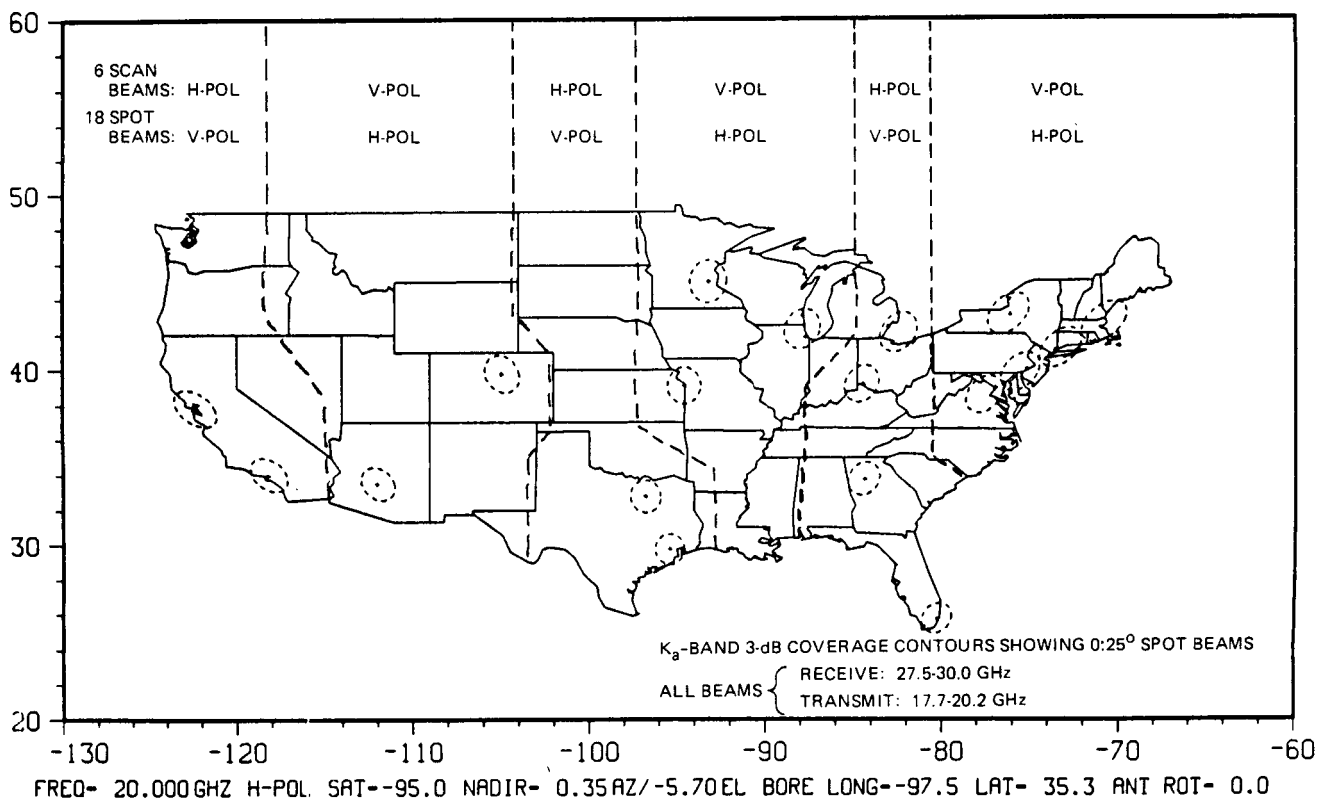


FIGURE 46. - K_A-BAND 3-dB COVERAGE CONTOURS FOR RCA PAYLOAD CONCEPT 4.

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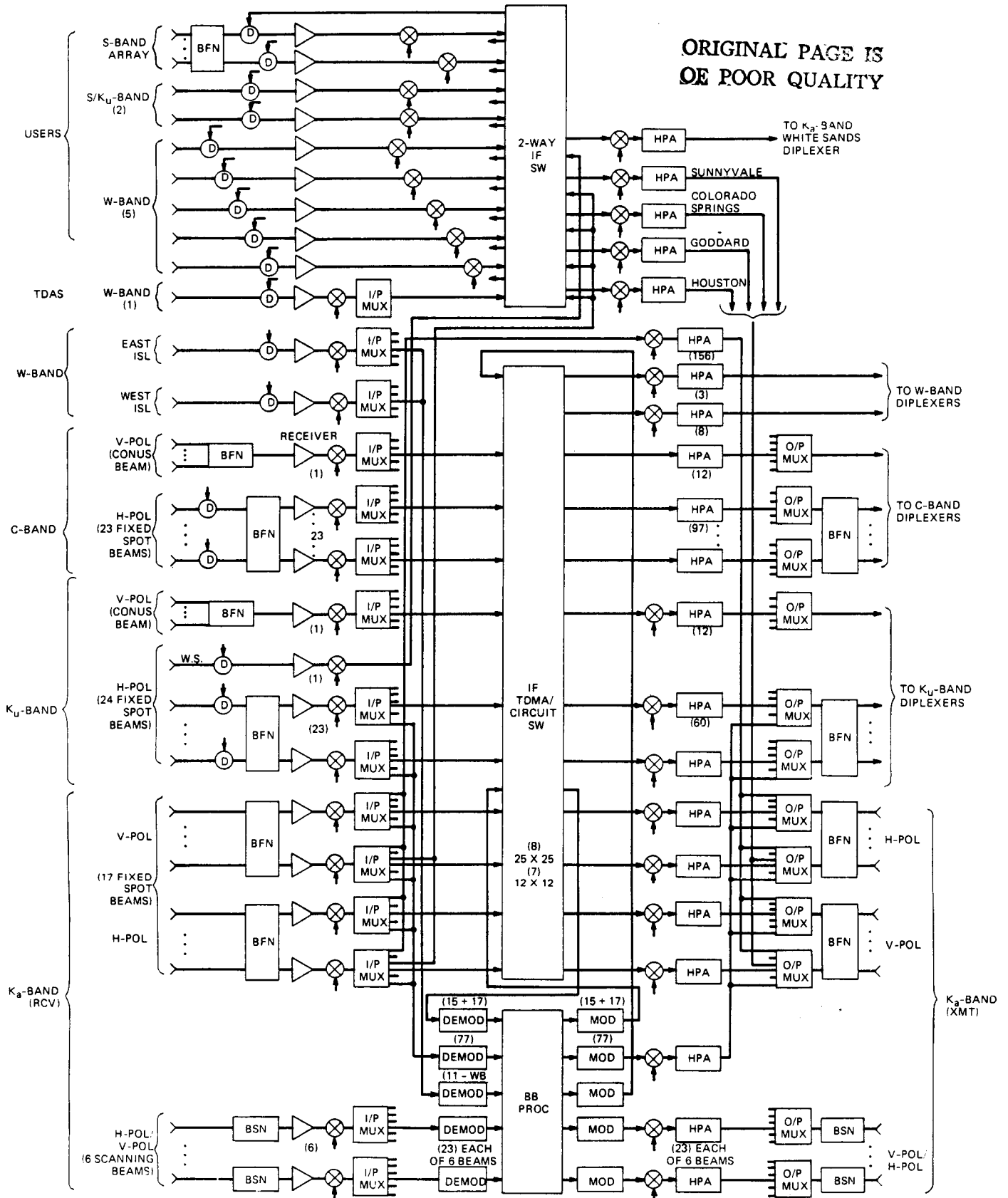


FIGURE 47. - BLOCK DIAGRAM OF RCA PAYLOAD CONCEPT 4.



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16. Abstract This report summarizes and compares the major results of two NASA sponsored studies that defined potential communications payload concepts to meet the satellite traffic forecast for the turn of the century for the continental United States and Region 2 of the International Telecommunications Union. The studies were performed by the Ford Aerospace and Communications Corporation and RCA Astro-Electronics (now GE-RCA Astro-Space Division). Future scenarios of aggregations of communications services are presented. Payload concepts are developed and defined in detail for nine of the scenarios. Payload costs and critical technologies per payload are also presented. Finally the payload concepts are compared and the findings of the reports are discussed.			
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